STEPHEN HAWKING WORLD EXCLUSIVE

Secrets of his life and unpublished theories

Special tribute issue

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Lucy Hawking

Lucy Hawking, Brian Cox, Lord Martin Rees Sir Roger Penrose, Neil deGrasse Tyson and more on

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Hawking experiences four minutes of weightlessness on a zero-g aircraft

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Welcome

On 14 March we woke to the news that world-renowned physicist Stephen Hawking had peacefully passed away at his home in Cambridge at the age of 76, succumbing to amyotrophic lateral sclerosis (ALS), commonly known as motor neurone disease (MND). Hawking had outlived the life expectancy of two years that doctors had given him back in 1963, going on to become one of the greatest minds of our time and, at the time of his death, a recipient of numerous awards, an author of exceedingly successful popular science books, the director of research at the Centre for Theoretical Cosmology at the University of Cambridge and a former Lucasian Professor of Mathematics. His scientific work saw him - among other things - make the prediction that black holes emit radiation, and he was the first to put together a theory that unifies the general theory of relativity and quantum mechanics.

I was extremely fortunate to meet Hawking in 2014 at a conference in Tenerife while working as the Senior Staff Writer for this very magazine; an interaction that I'll cherish for the rest of my life: Hawking had the perfect balance of inspiration, humour and approachability, he was a true star of science.

This month we honour his memory with our special issue, with tributes from his daughter Lucy Hawking, friends and colleagues.

Gemma Lavender
Editor

"His courage and persistence with his brilliance and humour inspired people across the world" **Lucy Hawking, Page 16**

Our contributors include...

Abigail Beall
Science reporter
Could there be life on Venus? It seems that it's one of the top places to look according to recent research – despite its hostility. Turn to page 54 for Abigail's report.

Ninian Boyle
Astronomer & writer
Ninian has the tutorials you need to try out this summer, from getting a young audience started in astronomy to the best deep-sky targets to be enjoyed with your scope.

Lee Cavendish
Staff writer & astronomer
Try Lee's selection of DIY space projects. There's something for everyone – from making your own telescope to building mission control.

Stuart Atkinson
Astronomer & author
Seek out the planets this month with Stuart's guide to the wanderers of Earth's sky. Turn to page 80 for his tips on which are visible and how you can get the best views.

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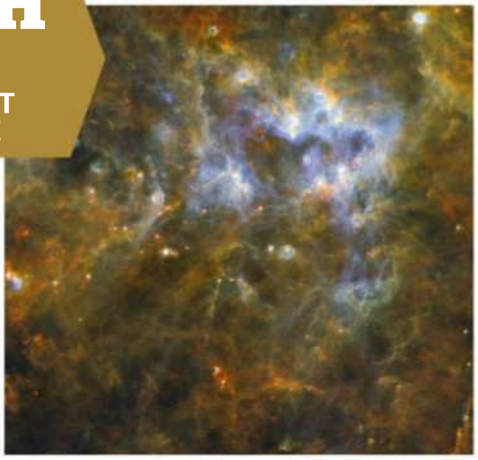

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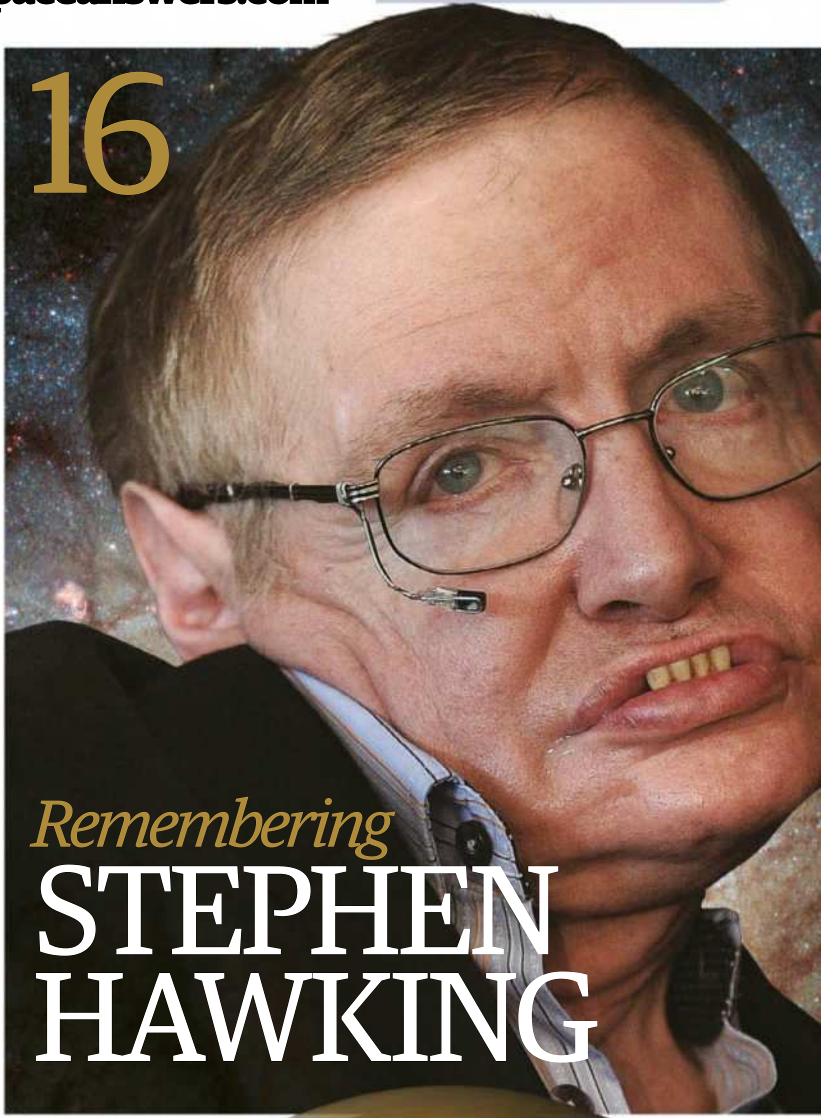

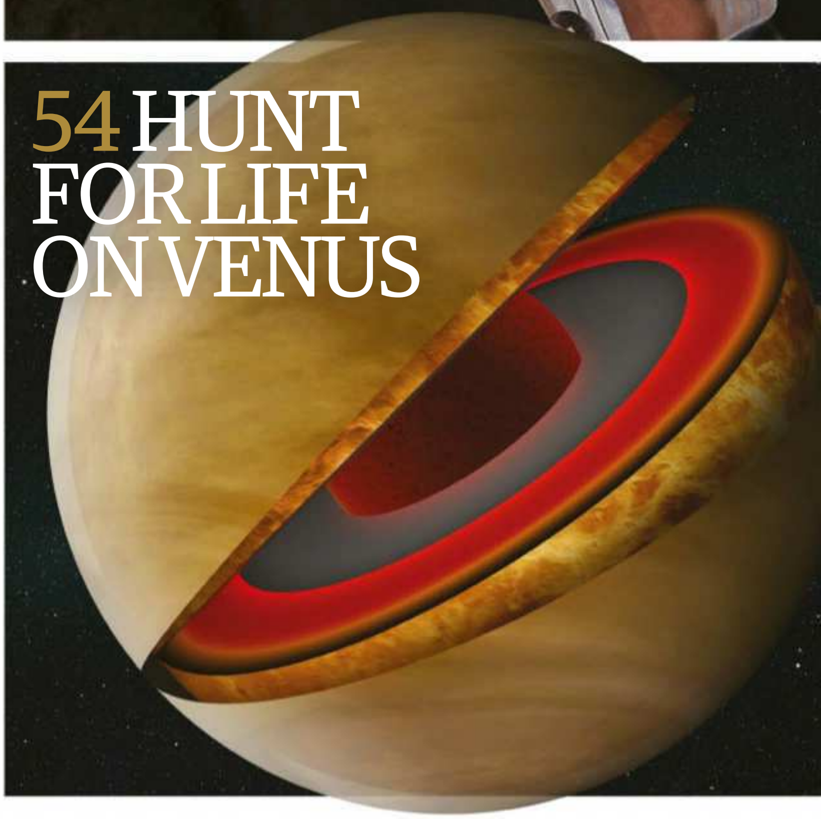

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"A future mission that I'd really like us to do would involve going to Titan"

32 Professor Mark McCaughrean
Senior science advisor, ESA

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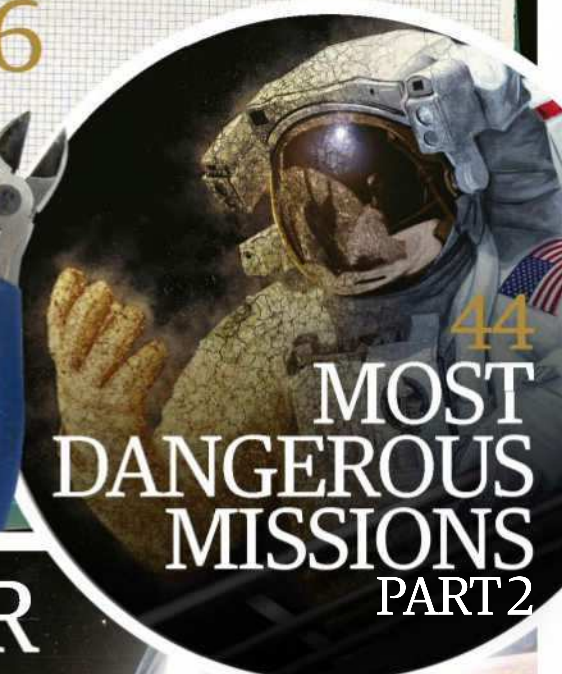

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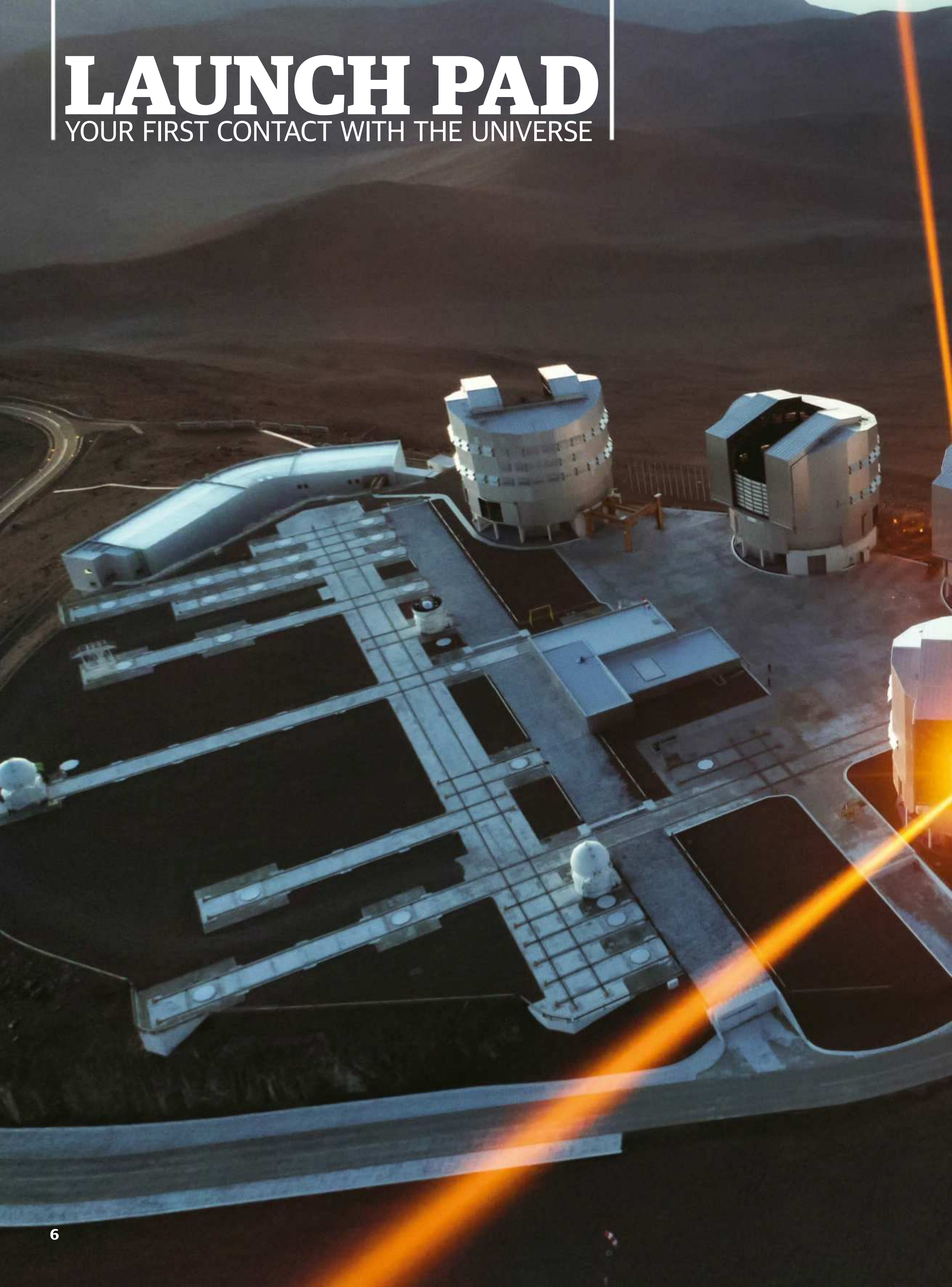


In the firing line of telescope lasers

Four lasers shoot from the 4 Laser Guide Star Facility, a state-of-the-art component of the Adaptive Optics Facility of the European Southern Observatory (ESO)'s Very Large Telescope (VLT). Its aim is to keep its seeing conditions under control since the turbulence of Earth's atmosphere causes stars to twinkle, which ordinarily causes a blurry view of the night sky. With this instrument, the VLT achieves a crystal-clear view of the cosmos.

Each of the intense orange beams is some 4,000-times more powerful than a standard laser pointer, creating an artificial guide star by exciting sodium atoms high in our planet's upper atmosphere and causing them to glow.

GRACE-FO has liftoff!

Blasting off into Earth orbit, the Gravity Recovery and Climate Experiment Follow-On – or GRACE-FO for short – makes a dramatic exit from our planet on 22 May from Space Launch Complex 4E at California's Vandenberg Air Force Base. The mission is a joint project between NASA and the German Research Centre for Geosciences and will measure how mass is redistributed within and among Earth's atmosphere, land, oceans and ice sheets, as well as within our planet itself.

GRACE-FO isn't on its own on its flight though, its sharing its ride with five Iridium NEXT communications satellites as part of a commercial rideshare agreement.

Jupiter's new perspective

It's just another extraordinary view of gas giant Jupiter captured by NASA's Juno spacecraft during its 12th close flyby of the planet. The new perspective of the king of the Solar System from the south makes the Great Red Spot appear as though its in the gas giant's northern territory.

Juno snapped the colour-enhanced image on 1 April. At the time of the planetary photoshoot, the spacecraft was between 17,329 kilometres (10,768 miles) to 68,959 kilometres (42,849 miles) above the Jovian cloud tops.

© NASA/JPL-Caltech

Hidden secrets of a stellar cradle

This is the 12,000-light-year distant G305 star-forming complex, a stellar nursery which is a cloudy and dusty place. Since they're so cold, these nebulae shine best in infrared light – a portion of the electromagnetic spectrum that's invisible to the human eye. In this particular image that was captured by ESA's Herschel space observatory, a number of bright, intricate gas clouds can be seen, heated by the infant stars in their midst. The bursts of star-forming hotspots stand out in blue tones, while cooler regions glow in red-brown.

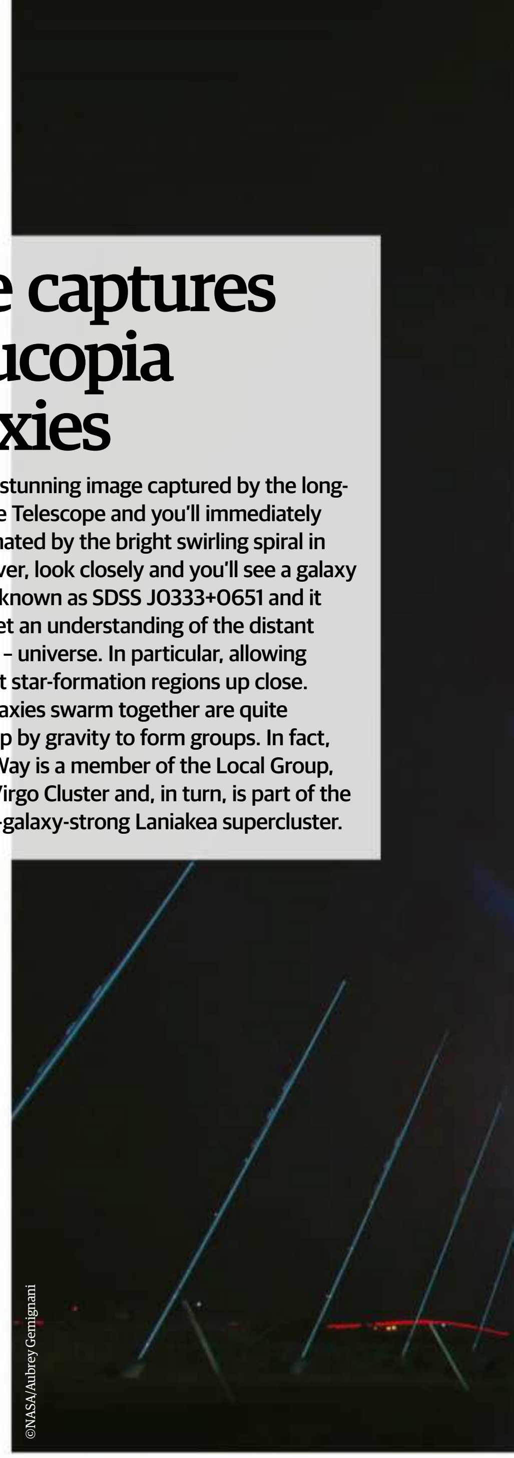
© ESA

© ESA/Hubble & NASA

Hubble captures a cornucopia of galaxies

A brief glance at this stunning image captured by the long-serving Hubble Space Telescope and you'll immediately realise that it's dominated by the bright swirling spiral in the lower left. However, look closely and you'll see a galaxy cluster behind it. It's known as SDSS J0333+0651 and it helps astronomers get an understanding of the distant – and therefore early – universe. In particular, allowing researchers to look at star-formation regions up close.

Clusters where galaxies swarm together are quite common, gathered up by gravity to form groups. In fact, our very own Milky Way is a member of the Local Group, which is part of the Virgo Cluster and, in turn, is part of the impressive 100,000-galaxy-strong Laniakea supercluster.



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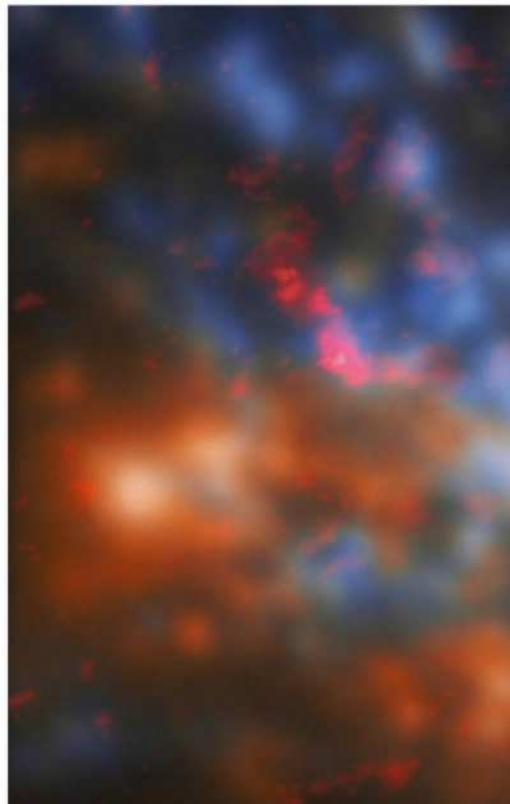
Titan: a world of its own

This visually arresting view of Saturn's largest moon Titan is just one of many stunning images captured by NASA's Cassini spacecraft before the mission ended in September 2017. The world, which is larger than the planet Mercury, measures 5,150 kilometres (3,200 miles) across – in this close-up, some of Titan's intriguing features are plain to see. Cassini's camera looks toward the dune-filled region known as Shangri-La, where the Huygens probe's landing site sits.

Look closely, and you'll be able to see the detached haze that surrounds Titan. Behind the moon are Saturn's rings.



Antares takes supplies to the Space Station

On board the Orbital ATK Antares rocket, the Cygnus spacecraft launches from Pad-0A at NASA's Wallops Flight Facility in Virginia on 21 May. This is Orbital ATK's ninth contracted cargo resupply mission with NASA to the International Space Station (ISS) to deliver approximately 7,400 pounds of science and research, crew supplies and vehicle hardware to the orbiting outpost and its astronauts.

Revealing a galaxy's centre

NGC 5643 is a Seyfert galaxy – structures that have luminous centres, which are thought to be powered by material falling onto a supermassive black hole.

The centres of Seyfert galaxies can be difficult to observe since they can be obscured by clouds of dust and intergalactic material. NGC 5643 in particular has posed the extra challenge of being orientated at a highly-inclined angle, making its centre tricky to see.

However, with the help of the Atacama Large Millimeter/submillimeter Array (ALMA), combined with data from the Multi Unit Spectroscopic Explorer (MUSE) instrument on the European Southern Observatory (ESO)'s Very Large Telescope, astronomers have been able to catch a glimpse, complete with an energetic outflowing of ionised gas pouring out into space caused by matter being ejected from the cosmic monster at the core.

Pluto could be 'one giant comet'

Researchers say the dwarf planet has stark similarities with Comet 67P, forcing them to review its status once again

Pluto's status has already changed once in recent times - from planet to dwarf planet - but now scientists are suggesting it may not be either of those. Instead, they hypothesise that Pluto may actually be a giant ball of comets, throwing a curve ball in the debate over the body's origins that is already proving controversial.

The claim is being made by Dr Christopher Glein, a scientist at the Southwest Research Institute in San Antonio, USA, and it centres on the nitrogen-rich ice in a large glacier called Sputnik Planitia, formed on the left lobe of the dwarf planet's heart-shaped Tombaugh Regio.

By taking data from the European Space Agency's Rosetta mission, which orbited Comet 67P between 2014 and 2016, and combining it with information from NASA's New Horizons 2015 mission to Pluto, the scientists were able to make a comparison. "We found an intriguing consistency between the estimated amount of nitrogen inside the glacier and the amount that would be expected if Pluto was formed by the agglomeration of roughly a billion comets or other Kuiper Belt objects similar in chemical composition to 67P," Dr Glein says. "We've developed what we call 'the giant comet' cosmochemical model of Pluto formation."

Described online in the journal *Icarus*, the study suggests the low abundance of carbon monoxide at Pluto points to burial in surface ices or to destruction from liquid water. "Our research suggests that Pluto's initial chemical make-up, inherited from cometary building blocks, was chemically modified by liquid water, perhaps even in a subsurface ocean," Dr Glein says.

The study also assessed a solar model which hypothesises that Pluto formed from very cold ices that would have had a chemical composition more closely matching our Sun. But scientists say the levels of nitrogen and carbon monoxide on Pluto are better explained by the comet theory. "Using chemistry as a detective's tool, we are able to trace certain features we see on Pluto today to formation processes from long ago," Dr Glein continues. "This leads to a new appreciation of the richness of Pluto's 'life story', which we are only starting to grasp."

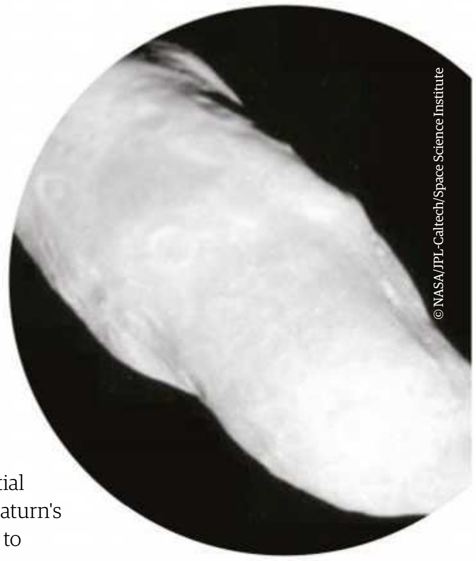
This theory has already come under fire. Alan Stern, who led the New Horizons mission, took to Twitter and called it a "silly conversation." "Pluto," he added, "is the size of a continent. Comets are the size of a mountain. If we categorised Pluto as a comet because its composition is like a comet then we'd call the Earth an asteroid."

"This leads to a new appreciation of the richness of Pluto's 'life story'"

New Horizons captured this image of Sputnik Planitia – a glacial expanse rich in nitrogen, carbon monoxide and methane ices

New study reveals reason for Saturn's 'odd-shaped' moons

They resemble ravioli, cigars and potatoes, and scientists think they know how that came to be



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Potato-shaped Prometheus as taken by NASA's Cassini spacecraft

Saturn's peculiar-shaped inner moons may have been formed by age-old mergers of similar-sized moonlets, according to a new study by scientists in Switzerland. If true, they say it would shed new light on how moons in general tend to form, and it would also be the first explanation covering the large range of odd shapes that have been observed in recent years.

Ever since the Cassini spacecraft began to study Saturn and its system, including its rings and natural satellites, in 1998 scientists have sought to explain why the moons have resembled all manner of different shapes. Pan and Atlas look like ravioli with their flat ridges and bulging middles, while Prometheus has been described as a potato.

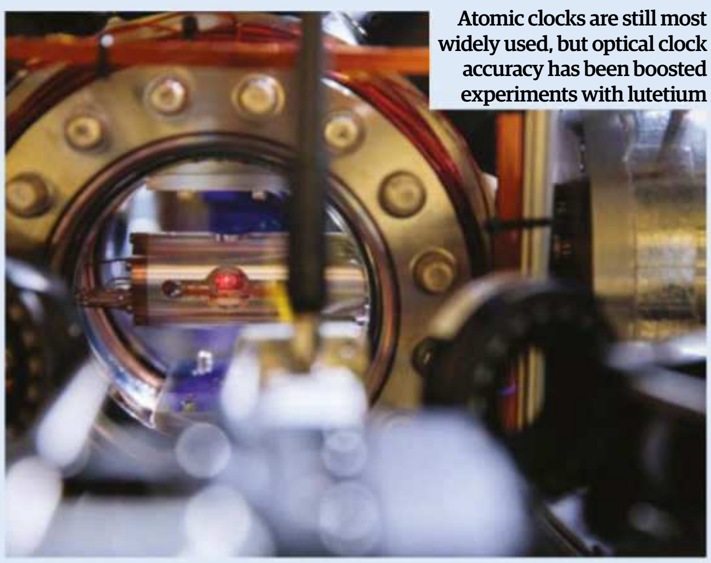
Computer simulations created by scientists at the University of Bern, however, have taken us one step closer to a better understanding. They ruled out a gradual accretion of material around a core, which is one of the most common theories explaining how celestial bodies form. This is because Saturn's gravitational pull is too strong to allow such a formation.

Instead they showed that collisions between tiny moonlets were far more likely. This so-called pyramidal regime would result in different shapes depending on the method of collision. A head-on smash would produce structures like Pan and Atlas. Impacts at oblique angles would create potato shapes.

"We found that 20 to 50 per cent of the small moons should display either an equatorial ridge or an elongated shape, while the rest should have more random potato-like shapes," said dynamist Adrien Leleu. "And this is the case. Considering the six inner moons Pan, Atlas, Prometheus, Pandora, Janus and Epimetheus, the first three display these features, while the others - Pandora, Janus and Epimetheus - have random shapes."

Atomic clocks look set to become more precise

Clocks using a neglected atom may become the best timekeepers



Atomic clocks are still most widely used, but optical clock accuracy has been boosted experiments with lutetium

© Centre for Quantum Technologies, National University of Singapore

A neglected rare-earth element is being used in a bid to create the most precise clocks ever built. Physicists at the National University of Singapore have discovered that lutetium (Lu) can be highly effective within optical clocks since it is relatively insensitive to changes in environmental temperature, meaning optical clocks would be able to run for longer.

Currently, global time and the control of GPS navigation is largely carried out using cesium atomic clocks, thanks to a decision by the International Committee for Weights and Measures in 1967 to define a second as the amount of time it takes for a cesium atom to absorb enough microwave energy to be excited.

Optical clocks have since emerged as being 100-times more precise, using higher frequencies of visible light rather than microwaves to excite atoms. But while the atoms used are aluminium or ytterbium, luterium has been found to be more reliable in such kinds of atomic clocks. There's a chance it could detect dark matter and dark energy too.

"We have definitively shown that Lu is the least sensitive to temperature of all established atomic clocks," says first author Kyle Arnold. "That will not only help to make a lab-based clock more accurate, but also make clocks that come out of the labs more practical, allowing them to operate in a wider range of environments."

© NASA/JPL-Caltech

Mars sample success for Curiosity rover

NASA's Martian mission has successfully bored a hole into the Red Planet's rocks after 18 months of inactivity

Curiosity's malfunctioning drill has been reactivated for the first time since December 2016, allowing the rover to successfully bore into the rock of Mars once again. Engineers had worked tirelessly to resolve the issue, which centred on a broken feed that was stopping the drill from extending between two stabilisers.

By using the force of Curiosity's robotic arm to push the drill forward beyond its stabilising posts the mechanical problems have been overcome. The rover has been able to bore five centimetres (two inches) into a target called Dulith using a technique called feed-extended drilling and it is, says NASA, similar to the way humans would drill into a wall at home.

"The team used tremendous ingenuity to devise a new drilling technique and implement it on another planet," said Curiosity deputy project manager Steve Lee of NASA's Jet Propulsion Laboratory. "Those are two vital inches of innovation from 60 million miles away. We're thrilled that the result was so successful."

It is important that Curiosity continues drilling because the samples of rock and soil it gathers can tell scientists so much about the Red Planet. The rover has two laboratories inside it that conduct chemical and mineralogical analyses and these can point to Mars' potential to host life and show how its climate has changed over time.

The engineering team is now looking at a new process for delivering those samples from the drill bit to the laboratories. Engineers will also use the rover's cameras to estimate how much powder trickles out when running the drill backwards.

Global warming triggered by dinosaur-slaying asteroid

The space rock that caused the extinction event saw Earth temperatures rise for tens of thousands of years

The asteroid which smashed into Earth about 65 million years ago and wiped out the dinosaurs looks to have caused the Earth's climate to warm for 100,000 years, researchers have claimed. An analysis of fossil records points to an overall increased temperature on our planet of five degrees Celsius (nine degrees Fahrenheit). While it's long been hypothesised that wildfires raging across the globe released carbon dioxide and raised temperatures, only now are scientists figuring out the length of time that lasted.

Dr Kenneth MacLeod, a geologist at the University of Missouri, led a research team in examining a collection of fossilised fish teeth, scales and bones from a paleontological site in northwestern Tunisia. They examined the concentration of different oxygen isotopes in the fossils, noting that the light oxygen isotope, oxygen 16, increases as temperatures rise. They were able to isolate samples dating 50,000 years before the impact, 100,000 years after and 200,000 years after that.

To their surprise, the results were clean and showed an average rise of 5°C (9°F). Dr MacLeod believes such global warming would have killed any animals that did not perish in the immediate aftermath of the asteroid collision.

© NASA Goddard

An artist impression of a massive asteroid impact on Earth, the likes of which killed the dinosaurs

NASA's plan for commercial ISS 'may not work'

Private investors may be put off by news that commercial space stations are unlikely to make a profit in the mid-2020s

Commercial space stations are unlikely to be financially viable by 2025 - the year NASA is set to end federal funding of the ISS, according to a study presented at a US congressional hearing. Bhavya Lal, of the Institute for Defense Analysis' Science and Technology Policy Institute, told the House Science Committee that investors are likely to be put off by uncertainty over costs and revenues. Of the four models studied by her organisation, only one proved viable - but even then it was based on the assumption that transportation costs would be at least half of what they are today.

Proposing that the International Space Station be extended to at least 2028 - at a cost to NASA of some \$3 to \$4 billion a year, Lal also put forward the possibilities of the ISS being part or fully privatised or the station being subsidised by NASA for commercial use. But while she conceded that some applications for a commercial space station could experience faster growth, she said: "Venture capitalists we spoke to indicated that projected revenue streams are too far in the future and too uncertain to warrant making significant investments today."

NASA is looking to end funding of the ISS in 2025 and it wants private companies to come forward with business plans

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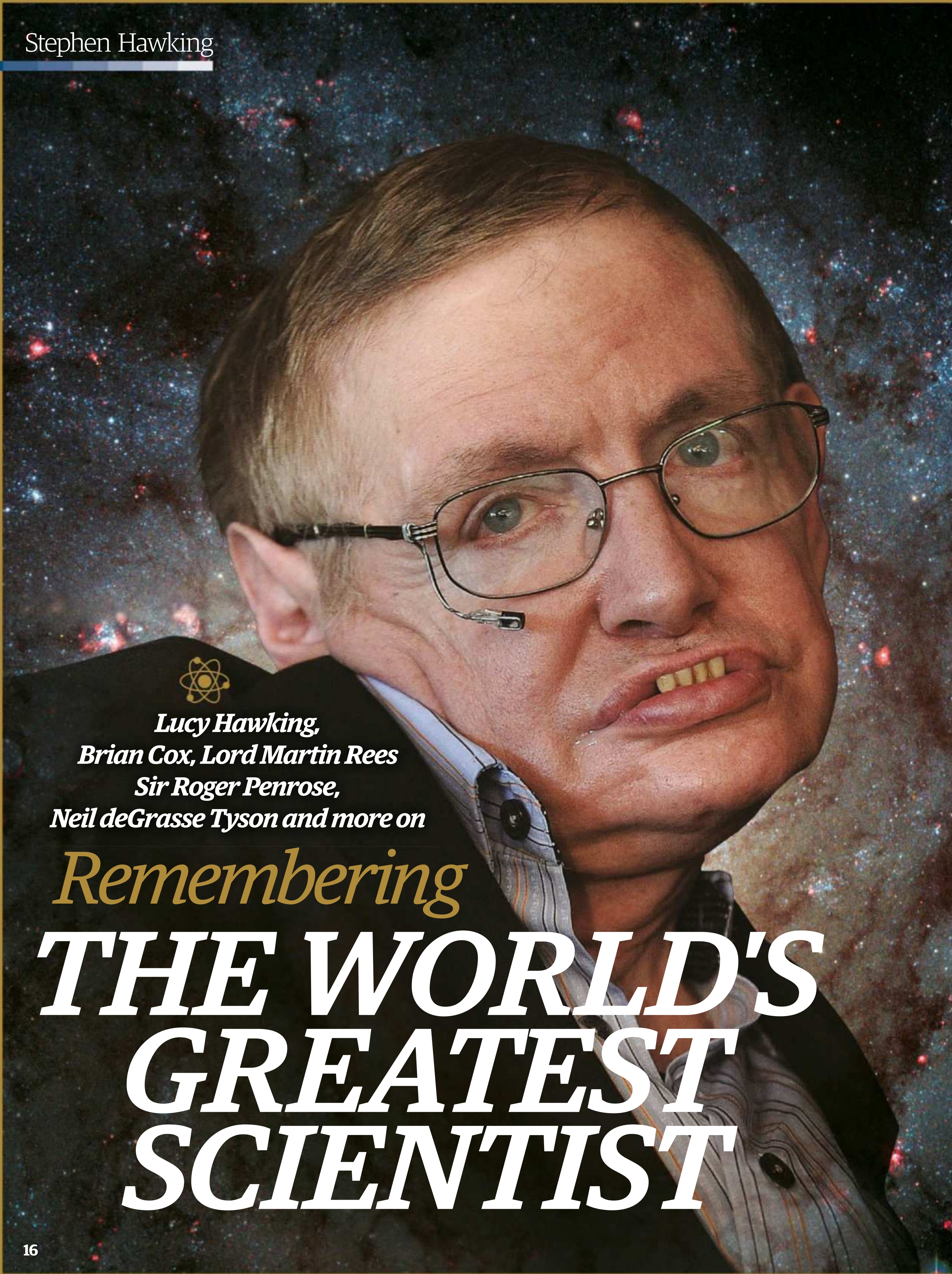


Lucy Hawking, Brian Cox, Lord Martin Rees Sir Roger Penrose, Neil deGrasse Tyson and more on

Remembering THE WORLD'S GREATEST SCIENTIST

Any discussion of Stephen Hawking's remarkable life is necessarily a binary one. There's his body of work, perhaps unmatched among modern physicists, and there is the man himself, instantly recognisable thanks to his wheelchair and distinctive computer-generated voice.

Combined, they provide the evocative image of a mind voyaging among the stars despite the frustrations imposed by its body, and Hawking's story is one of such triumph against the odds that it's almost impossible to separate the two threads.

Born 8 January 1942, exactly 300 years after the death of Galileo, Stephen William was the eldest of Frank and Isobel Hawking's four children, with two younger sisters and an adopted brother. His parents both studied at Oxford, his father reading medicine and his mother philosophy, politics and economics. His father's work in parasitology frequently took him to Africa. He was there at the outbreak of WWII, and took a journey across the continent to meet a ship bound for England; despite his attempts to volunteer for military service, his medical research was deemed more important. The family settled in St Albans, Hertfordshire, where their habit of travelling in a converted London taxi and spending mealtimes in silence, all reading books, gained them a reputation for eccentricity. They owned a former gypsy caravan parked in a field near Weymouth, Dorset, as a holiday home, until the county council removed it.

Sent to a 'progressive' school in Highgate, London, that failed to teach him to read (he finally managed it aged eight) Hawking nevertheless passed his Eleven Plus exam a year early and attended independent schools in Hertfordshire. His father's wish that he attend the prestigious Westminster School didn't come to fruition, as Hawking was ill on the day of the scholarship exam that would have allowed his parents to afford its fees. When not at school, Hawking spent his teenage years playing with model trains, none of which worked very well, and building toy aircraft and boats. "My aim was always to build working models that I could control," Hawking wrote. "I didn't care what they looked like." He also created complicated games with a friend, including a war game played on a board with 4,000 squares. "I think these games, as well as the trains, boats and airplanes, came from an urge to know how systems worked and how to control them... If you understand how the universe operates, you control it, in a way."

Though not initially successful in his studies Hawking showed a flair for the sciences and, having picked up the nickname 'Einstein', chose to study physics and chemistry at University College Oxford – the same college his father, who wanted him to study medicine, had attended – aged just 17.

Physics, described by Hawking as "the most boring subject at school because it was so easy and obvious", became more interesting to him, despite chemistry's potential for unexpected explosions,

A brief history of Hawking

1959
Begins studying at University College, Oxford, aged 17.

1962
Becomes a doctoral student at Cambridge under Dennis Sciama.

1963
Diagnosed with amyotrophic lateral sclerosis following a fall while ice skating.

1970
With Penrose, publishes a proof that the universe must have begun as a singularity.

1973
Publishes his first academic book: *The Large Scale Structure of Space-Time*, co-written with George Ellis.

1974
Elected a Fellow of the Royal Society, several weeks after the announcement of Hawking radiation.

1979
Elected Lucasian Professor of Mathematics at the University of Cambridge.

1981
Proposes that information in a black hole is irretrievably lost when a black hole evaporates, igniting a 'black hole war' with Susskind and 't Hooft.

1984
First draft of *A Brief History of Time* completed. Publisher thinks it's too technical.

1985
Contracts pneumonia and undergoes a tracheotomy. Loses power of speech.

1988
A Brief History of Time published. The book goes on to sell over ten million copies worldwide.

1988
Jointly with Penrose, wins the Wolf Prize in Physics worth $100,000, "for their brilliant development of the theory of general relativity".

1989
Appointed a Companion of Honour in the Birthday Honours, but turns down a knighthood.

1991
A film version of *A Brief History of Time*, produced by Steven Spielberg, premieres.

1997
A six-part documentary series, *Stephen Hawking's Universe*, is made.

2004
Admits he was on the wrong side in the 'black hole war', and buys Preskill an encyclopedia.

2005
Writes *A Briefer History of Time* with Leonard Mlodinow to update his ideas and make them more accessible.

2007
Publishes *George's Secret Key to the Universe* with his daughter Lucy.

2009
Holds party for time travellers. None show up.

2009
Receives Presidential Medal of Freedom from Barack Obama.

because it "offered the hope of understanding where we came from and why we are here". It came naturally to him, his physics tutor, Robert Berman, remarking: "It was only necessary for him to know that something could be done, and he could do it without looking to see how other people did it."

Being much younger than his peers, many of whom had come to university after doing military service, Hawking stood apart, feeling rather lonely. He joined the university rowing club (something he described as "fairly disastrous"), suffering head-on collisions, disqualification and eventually coxing a crew through dangerous waters that led to the boat getting damaged. He cultivated interests in music and science fiction and made friends, but experienced clumsiness that led to falls and difficulty with rowing.

An anti-work culture at Oxford at the time led to problems when it came to Hawking's final exams. Having calculated he carried out just 1,000 hours of study over the three years of his degree, Hawking was unprepared and planned to answer only some of the questions. Despite this he placed right on the border between first- and second-class honours, using a viva examination in which he promised to leave Oxford for Cambridge if awarded a first to tip himself over in to the higher category.

In 1962 Hawking kept his word and joined Trinity Hall college, Cambridge, as a doctoral student. He applied to work with Fred Hoyle – the astronomer whose 1954 paper launched stellar nucleosynthesis, the study of how stars fuse elements to create heat and light – but was disappointed to be assigned to Dennis Sciama, a physicist he was unfamiliar with. Today considered one of the fathers of modern cosmology, Sciama is known for his work on radio astronomy, dark matter, quasars, the cosmic background radiation, black holes and general relativity. In addition to Hawking his students have included Lord Martin Rees, the Astronomer Royal; quantum computing pioneer David Deutsch; emeritus distinguished professor of complex systems at the University of Cape Town George Ellis and Oxford University professor of physics James Binney.

Having not studied mathematics since he left school Hawking found cosmology and general relativity a struggle, but they were the areas he was determined to work in. His alternative field, the study of elementary particles, was too much like "botany" for his tastes, and many of the prevailing theories of the time turned out to be wrong. "I'm very glad I didn't start my research into elementary particles," Hawking wrote later. "None of my work from that period would have survived."

Hawking's clumsiness became more of an issue during his time at Cambridge. After being told by a doctor he should drink less, it took an incident while ice skating at Christmas for him to be referred to a specialist. After two weeks of tests all that he was told was that his condition wasn't multiple sclerosis, but that he was an atypical case, and he didn't ask for more details. Eventually he was told he had amyotrophic lateral sclerosis (ALS), a form of motor neurone disease characterised by gradually worsening muscle weakness, and given two years to live. This was 1963, and he was just 21.

Hawking's daughter: Lucy Hawking

"We will miss him forever"

"My father used to just cause absolute consternation. People would just stop and stare – my father had his own electric wheelchair, which he used to drive at great speed across the whole of Cambridge, accompanied by me and my two older brothers, sort of like blonde little moppets running alongside with our ice creams – I think in horror, amazement and shock. How was this disabled man by himself? What were these children doing? People just couldn't process the sight. My father always had lots of scientific colleagues who would come for dinner pretty much every night and they would discuss extraordinary topics. No topics were out of bounds. As a child, you could ask any question you wanted and get a reply. It was my son's eight or ninth birthday party and one of my son's friends went up to my dad and asked: 'Stephen, what would happen to me if I fell into a black hole?' Everyone was really interested and everyone waited for the answer. My father told him that he would be turned into spaghetti and of course, all the kids were thrilled and they totally understood his answer, and the adults pretended to.

"People who live in really extreme circumstances, for example in war zones, seemed to find something very, very inspirational in his example of perseverance and persistence and his kind of ability to rise above his suffering and still want to communicate at a higher level with humour to a world population. Some children knew him as a genius, others knew him as a disabled man.

"His courage and persistence with his brilliance and humour inspired people across the world. He once said, 'It would not be much of a universe if it wasn't home to the people you love'. We will miss him forever."

Hawking was diagnosed with amyotrophic lateral sclerosis (ALS) during his early life

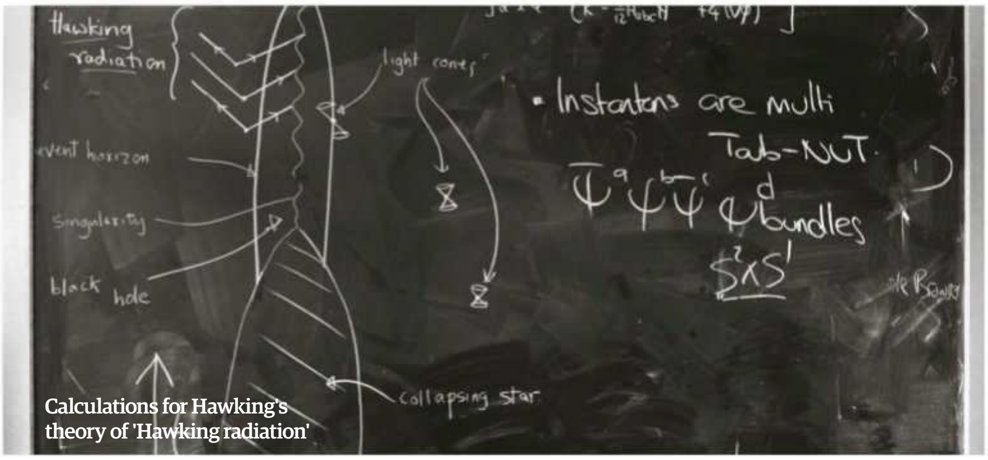
Hawking predicted that radiation is leaked by black holes

Hawking theory #1

Black holes leak radiation

THEORY NO PROVEN?

Hawking's most famous theoretical discovery, and one he was sad not to have won a Nobel Prize for, although he conceded it was hard to test experimentally. The radiation is predicted to be released by black holes, and can cause them to eventually evaporate if they're not kept topped up with new matter and energy. In September 2010, an experiment at a lab in Italy produced a result that looked very much like Hawking radiation, but remains unverified. NASA's Fermi Space Telescope, however, may yet provide the proof that's needed as it hunts for gamma ray flashes. Sadly, Nobel prizes are not awarded posthumously.



Calculations for Hawking's theory of 'Hawking radiation'

It is often reported that Hawking became depressed and began drinking heavily at this time, but he denies this, admitting to little worse than listening to Wagner. "Before my condition was diagnosed," he wrote, "I had been very bored with life. But shortly after I came out of the hospital... I realised that there were a lot of worthwhile things I could do." He returned to his work, the disease progressing much more slowly than doctors had predicted, and became engaged to Jane Wilde. "This gave me something to live for," he wrote.

A great debate in physics at the time was the Big Bang theory – the one we're familiar with today in which the universe has a defined beginning – versus the Steady State theory, which held that the universe had always been the way it is, with the continuous creation of matter allowing it to remain that way despite the universe's observable expansion. Hoyle was a major proponent of the Steady State, and while Sciama initially supported it he would abandon the theory when the evidence mounted against it. Hawking publicly challenged Hoyle over his new theory of gravity at a 1964 Royal Society lecture, appearing to calculate in his head something he had in fact had time to work on, as he had been sharing an office with Hoyle's student and read a draft of the lecture. Hoyle was furious, but would later offer Hawking a job.

First, though, he needed to finish his PhD. He wrote a thesis on singularity theory inspired by the work of Roger Penrose, now the emeritus Rouse Ball professor of mathematics at the University of Oxford. Penrose showed that a star would collapse into a singularity even if it wasn't perfectly spherical, but Hawking realised that the same argument could be applied to the whole universe, and this proved that space-time had a beginning. The thesis' acceptance in 1966, along with a fellowship grant from a Cambridge college, allowed Hawking to get married to Jane and eventually buy a house, although the increasing weakness of his muscles was making it harder for him to walk and give lectures. Then in May 1967, their first child, Robert, was born.

Hawking's work on singularities continued, and working together with Penrose he published a proof that the universe must have started as one if it also satisfies a few other conditions. The 1970s proved to be a fruitful period for his mind, beginning with the second law of black hole dynamics – that a black hole's event horizon cannot shrink – in 1970, then four more laws of black hole mechanics in association with other academics. His daughter Lucy was also born that year. He published an award-winning essay on black holes in 1971, and his first book, *The Large Scale Structure of Space-Time*, written with George Ellis and dedicated to Sciama, was published in 1973. Hawking would go on to describe the book as "highly technical" and wrote: "I

Fellow physicist: Professor Brian Cox

"One of the great things about Stephen was that he became quite political"

"He is rightly described as one of the great scientists, and that's for several reasons. His initial paper was on Einstein's theory of general relativity, published in 1915 and what we understand to be the framework of the universe. And he proved that, given just that theory, there has to be an origin of time. So, he essentially proved that not long after his thesis – it was part of his thesis at Cambridge and called the singularity theorem. Hawking then moved on to black holes, proving that they're not entirely black. A common picture of a black hole is that when you throw something into it, it never comes back. Nothing can escape, not even light. But Hawking showed that that wasn't right. He showed that they have a temperature and they glow and that they radiate out into space and ultimately, over really long times, they evaporate away, and that's called Hawking radiation. Hawking took us to the next step in proving Einstein's theory of relativity; it's the next step to the theory we hope is there – it's the theory we need to understand the universe. It's like what Hawking said beautifully at the end of *A Brief History of Time*: he said, 'If we know all of this, we'll know the mind of God'. But of course he was talking about nature there, he wasn't a religious man. Einstein used to talk in a similar way. They both believed there's an idea, a regularity and beauty that underpins the universe.

"I got to know Stephen later in life and he was very funny. One thing I did with him was Monty Python at the O2. Eric Idle asked me if I could get Stephen to do a sketch with them so I emailed him, and within about a minute an email came back from Stephen saying yes. We went down to Cambridge for it. I'm always criticising in a gentle way Eric's songs because they're not really accurate. There's a song called the Galaxy Song which talks about the Earth going around the Sun in a circle. And I say it's not a circle, it's an ellipse. It's scientifically inaccurate. So Eric came up with this sketch where I would be criticising the *Galaxy Song* and then in the background, there is a speck coming past King's College and it's Stephen in his wheelchair and he runs me over and says, 'I think you're being pedantic', and Stephen starts singing the *Galaxy Song*. The 'I think you're being pedantic' was an ad lib and he did it with perfect comic timing. At the time, he was finding it very difficult to type things into his computer. He was very funny, he wasn't in any way some dusty scientist.

"I have to say that one of the great things about Stephen was that he became quite political. He talked about how valuable science is as a way of thinking, a humble and careful way of thinking, and how our future should be bright – there are a lot of things to do and understand as individuals and as members of the human race. In order to do that, we have to think about our position in the universe as one civilisation. He became very active in putting over that point of view; he [often questioned] how can science influence how we behave. I think that was extremely important, he had a big voice. He also pointed out [humanity's] stupidity; how we had the tendency to look inwards rather than outwards with our petty internal conflicts rather than thinking about our wider value."

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would caution the general reader against attempting to consult it." Despite this, it has been reprinted several times.

The year 1973 also saw a shift in Hawking's work as he became more interested in quantum mechanics, particularly where the theory intersects with gravity, following a visit to Moscow where he met Yakov Borisovich Zel'dovich and Alexei Starobinsky, who had shown that rotating black holes emit particles, breaking the second law of black hole dynamics. In 1974 Hawking was able to show – controversially at the time – that black holes emit radiation, something now known as Hawking radiation, which if not replenished can cause a black hole to evaporate. The same year he was elected a Fellow of the Royal Society, one of the youngest to receive the honour at the time.

It's worth noting that, at the time, there was no observational evidence for black holes – they existed purely in the theoretical work of various physicists. Hawking's sense of humour frequently shone through the complex nature of his professional life, and the bets he made during his career, often planning to lose them, are a good example of this.

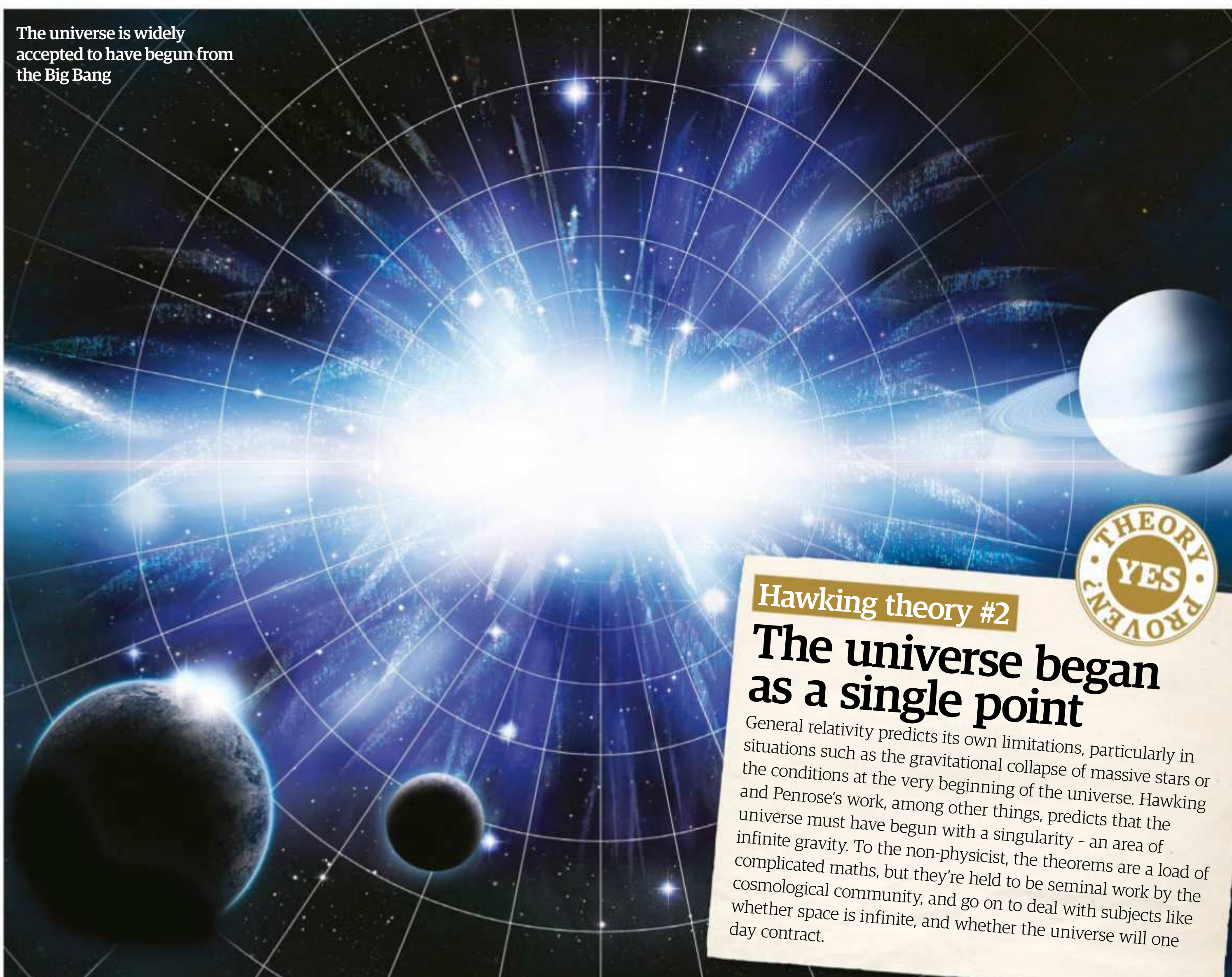
Hawking's successor: Michael Green

"It's going to be difficult to live up to him"

"Stephen Hawking's name carries a certain weight with it and it's extremely difficult to imagine one would live up to it [Green will take over as Lucasian Professor of Mathematics at Cambridge]. His name comes up all the time; he had an influence on my work. He pinpointed an interface between general relativity, statistical mechanics and thermodynamics and quantum mechanics, and he put them all together. It raised the possibility of a very ambitious meta-unification of ideas and, at the same time, it raised some puzzles. Black holes appear to be, in some senses, like quantum mechanical objects, but in some senses they seem to violate our ideas about quantum mechanics.

"Perhaps it's because of the fact he's so physically restricted, or perhaps it would have been the case anyway, but there's a certain quality to the way he works and the style of results he produces which is very different from the run-of-the-mill theoretical physics paper.

"His work has been dramatically important in several instances over a long period of time. Added to that is this extraordinary physical handicap, and the fact that he's able to do anything is remarkable. If I get a headache, I can't work, but he seemed to be able to produce stuff despite fantastic problems."



The universe is widely accepted to have begun from the Big Bang

Theory proven? YES

Hawking theory #2

The universe began as a single point

General relativity predicts its own limitations, particularly in situations such as the gravitational collapse of massive stars or the conditions at the very beginning of the universe. Hawking and Penrose's work, among other things, predicts that the universe must have begun with a singularity – an area of infinite gravity. To the non-physicist, the theorems are a load of complicated maths, but they're held to be seminal work by the cosmological community, and go on to deal with subjects like whether space is infinite, and whether the universe will one day contract.

Hawking originally thought that black holes couldn't radiate – that is until he performed a lengthy calculation

THEORY PROVEN? YES

Hawking theory #3

The Bekenstein-Hawking formula

The second law of thermodynamics requires black holes to have entropy. Israeli-American physicist Jacob Bekenstein built on Hawking's work to show that the amount of entropy was proportional to the area of its event horizon, and was able to extend the second law to include black hole systems. Hawking originally opposed Bekenstein, claiming black holes could not radiate, but changed his mind after performing a lengthy calculation that led to the proposal of Hawking radiation.

Hawking celebrating 50 years as a fellow of Gonville & Caius College, Cambridge

> "Hawking's sense of humour frequently shone through the complex nature of his professional life"

In 1974 he bet the American physicist Kip Thorne that Cygnus X-1, a strong X-ray source around 6,100 light years from the Sun, wasn't a black hole. The bet wasn't for money, however. Thorne's wager was a four-year subscription to *Private Eye*, while Hawking put up a single year's worth of *Penthouse* magazine, calling the bet an "insurance policy" in case all his work on black holes was wrong – at least he'd have something to read. By 1990 there was so much evidence for black holes that Hawking conceded. Speaking in a 1997 TV documentary, Thorne alleged Hawking broke into his office and placed his thumbprint on the original handwritten bet, acknowledging he had lost. In the same film Hawking says with a grin: "I had given Thorne a subscription to *Penthouse*, much to his wife's disgust."

Thorne invited Hawking to the California Institute of Technology in Pasadena, where he encountered an electric wheelchair for the first time. Already notorious for the wild and erratic way he drove his manual wheelchair, and for illegally carrying passengers in his electric three-wheeled car, he enjoyed the extra independence the powered chair gave him. His links with Caltech stretch back to 1970 when he was appointed the Sherman Fairchild distinguished visiting professorship, and he spent a month there almost every year. He returned to Cambridge in 1975 to a new post, reader in gravitational physics, and began to attract recognition, winning the Eddington Medal from the Royal Astronomical Society and the Pius XI Gold Medal, presented by the Pope. He was minded to reject this latter honour, but recalled that the Vatican had pardoned Galileo. While in Italy he met Paul Dirac, one of the founders of quantum physics, who had told the Pontifical Academy of Sciences to award the medal to Hawking.

In 1974 Hawking was a research assistant. Three years later he progressed to professor of gravitational physics, and in 1979 he became the Lucasian Professor of Mathematics at Cambridge – a post founded in 1663 and once held by Dirac, Charles Babbage and Sir Isaac Newton (and, if *Star Trek: The Next Generation* is to be believed, by Lt Cmdr Data in the 24th century). The Hawkings' third child, Tim, was also born around this time, but Hawking's ALS continued to worsen, the muscle weakness bringing on fits of choking. He accepted home nursing services reluctantly.

Hawking visits the Temple of Heaven in Beijing in 2006

Hawking's colleague: Sir Roger Penrose

"Being a student of his was not easy… he ran his wheelchair over the foot of a student who caused him irritation"

"Those who knew Hawking would clearly appreciate the dominating presence of a real human being with an enormous zest for life, great humour and tremendous determination, yet with normal human weaknesses, as well as his more obvious strengths. It seems clear that he took great delight in his commonly perceived role as 'the #1 celebrity scientist'; huge audiences would attend his public lectures, perhaps not always just for edification.

"[In the scientific community] he was extremely highly regarded in view of his many greatly impressive, sometimes revolutionary contributions to the understanding of the physics and the geometry of the universe. Despite being diagnosed shortly after his 21st birthday as suffering from a then-unspecified incurable disease, he didn't succumb to depression – as others might – but began to set his sights on some of the most fundamental questions concerning the physical nature of the universe. In due course he would achieve extraordinary successes against the severest physical disabilities. Defying established medical opinion, he managed to live another 55 years.

"He was an extraordinarily determined person. He would insist that he should do things for himself. This, in turn, perhaps kept his muscles active in a way that delayed their atrophy, thereby slowing the progress of the disease. Nevertheless, his condition continued to deteriorate until he had almost no movement left, and his speech could barely be made out at all except by a very few who knew him well. He contracted pneumonia while in Switzerland in 1985, and a tracheotomy was necessary to save his life. Strangely, after this brush with death the progress of his degenerative disease seemed to slow to a virtual halt. His tracheotomy prevented any form of speech, however, so acquiring a computerised speech synthesiser became necessity.

"Hawking had many students, some of whom later made significant names for themselves. Yet being a student of his was not easy. He had been known to run his wheelchair over the foot of a student who caused him irritation.

"Despite his terrible physical circumstance, he almost always remained positive about life. He enjoyed his work, the company of other scientists, the arts, the fruits of his fame, his travels. He took great pleasure in children, sometimes entertaining them by swivelling around in his motorised wheelchair. Social issues concerned him. He promoted scientific understanding. He could be generous and was very often witty. He could display something of the arrogance that is not uncommon among physicists working at the cutting edge, and he had an autocratic streak, yet he could also show a true humility that is the mark of greatness."

The world remembers a "brilliant and funny" man

The famous physicist is remembered by some of the world's greatest scientists, public figures and entertainers

"His passing has left an intellectual vacuum in his wake, but it's not empty. Think of it as a kind of vacuum energy permeating the fabric of space-time that defies measure."
Astrophysicist Neil deGrasse Tyson

"Have fun out there among the stars."
Former US President Barack Obama

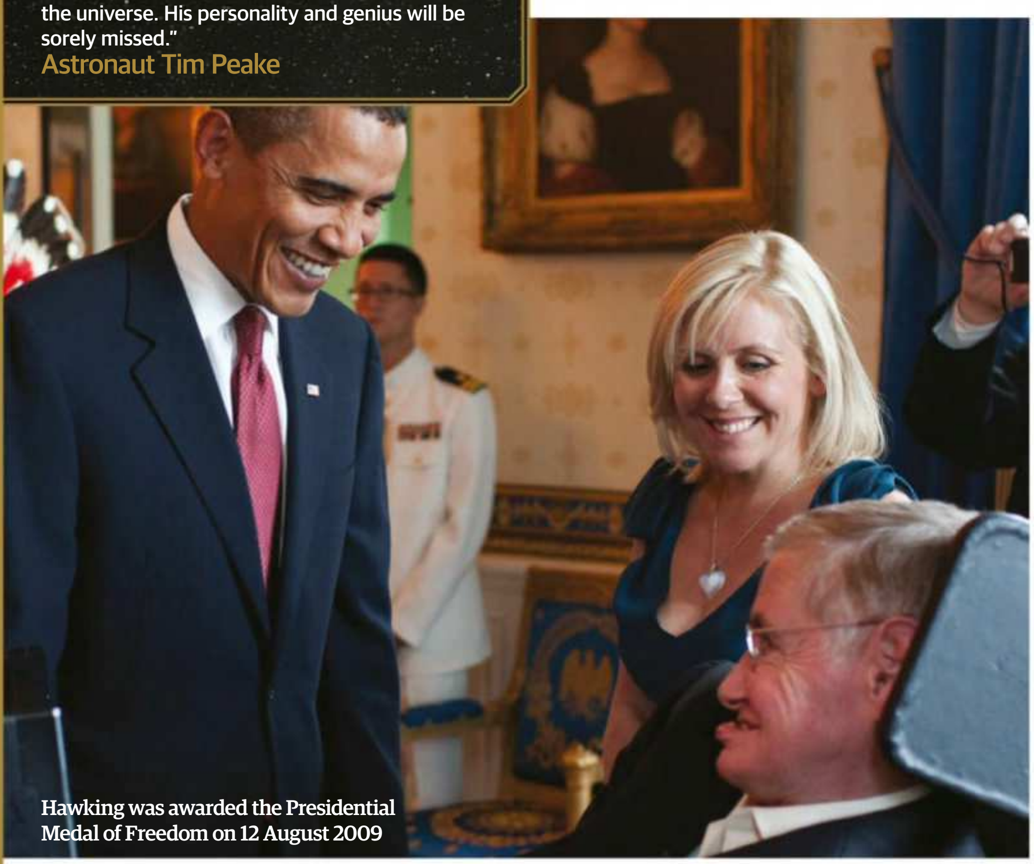
"Stephen Hawking was the funniest man I have ever met."
Actor Eddie Redmayne

"With grace, wit and courage, his genius took us all to the very edge of space and time."
Physicist Brian Greene

"We will always be inspired by his life and ideas."
Apple CEO Tim Cook

"He had a wickedly funny sense of humour. He virtually created the publishing genre of popular science. I will miss our margaritas but will raise one to the stars to celebrate your life."
Actor Benedict Cumberbatch

"He inspired generations to look beyond our own blue planet and expand our understanding of the universe. His personality and genius will be sorely missed."
Astronaut Tim Peake



Hawking was awarded the Presidential Medal of Freedom on 12 August 2009

Changes also came in his work. His previous insistence on mathematical proofs became less important, and he became more speculative in his theoretical work. "I would rather be right than be rigorous," he famously said to Thorne, and returned to the subject in his later writings: "It is almost impossible to be rigorous in quantum physics, because the whole field is on very shaky mathematical ground." In 1981, his proposal that information, or the relationships between particles, contained in a black hole is lost when it evaporates – a violation of quantum mechanics – set off what sounds like the greatest sci-fi film never made, the 'black hole war', with physicists Leonard Susskind and Gerard 't Hooft. Quantum mechanics and relativity are fundamentally incompatible, and the debate led to 't Hooft's development of the holographic principle – that the information is preserved on the boundary of the system through bumps in the event horizon – that's now part of string theory.

Hawking's mind began to be occupied by the theory of the beginning of the universe. Cosmological inflation, the idea that the universe expanded extremely rapidly at first before slowing down, was new and exciting, and Hawking's work in this period suggested that before the Big Bang time simply didn't exist, and that while the universe has no boundaries it does have a shape. A consequence of this was explored in a 1985 paper that theorised that if the universe stopped expanding and began to collapse, time would run backwards. It was later withdrawn, but this didn't stop the flow of awards and recognition, with Hawking becoming a CBE. His ideas here led to work beginning on his book *A Brief History of Time*.

It was around this time that Hawking began using the speech-generating device that became such a recognisable part of his public image. Its American accent was the only one available on the early model, which ran on an Apple II computer, but even when other accents became available he chose to stick with the original, saying: "I keep it because I have not heard a voice I like better."

The incident that led to the loss of his speech was more serious, however. In 1985 Hawking was visiting CERN, the particle accelerator laboratory on the border of France and Switzerland, when he contracted life-threatening pneumonia. His condition deteriorated so badly that his wife was asked if she wanted to withdraw life support – she refused and had him flown by helicopter to Addenbrooke's Hospital in Cambridge, but a tracheotomy was carried out to help him breathe. This permanently took away his ability to speak. While he recovered he needed round-the-clock nursing care, and one of those employed was Elaine Mason, who would become his second wife.

> "I wanted to explain how far I felt we had come in our understanding of the universe"
> **Prof Stephen Hawking**

The number of revisions required to make *A Brief History of Time* accessible to a non-specialist reader irritated Hawking, and he began using an assistant to help him finish writing it. Prior to this he had given lectures through an interpreter and written papers by dictating to a secretary, and he would go on to write several books using the speech synthesis program, which would be upgraded various times, moving from Apple systems to Intel.

A Brief History of Time cemented Hawking as one of the world's pre-eminent scientific minds. Hawking had first had the idea to write it in 1982, writing: "I wanted to explain how far I felt we had come in our understanding of the universe: how we might be near finding a complete theory that would describe the universe and everything in it." He chose the book's publisher, Bantam, because its books were widely available at airports, and was influenced by the BBC documentary series *The Ascent of Man*, which traced the development of human society. "I was sure that nearly everyone is interested in how the universe operates," he wrote, "but most people cannot follow mathematical equations. I don't care much for equations myself. I think in pictorial terms, and my aim in the book was to describe these mental images in words, with the help of familiar analogies and a few diagrams."

Published in 1988, the book would go on to sell over ten million copies worldwide. *Newsweek* featured Hawking on its cover, bestowing the title 'Master of the universe' on him, but it wasn't all

Hawking will forever be remembered as one of the greatest minds of the 20th century

"If you understand how the universe operates, you control it, in a way"

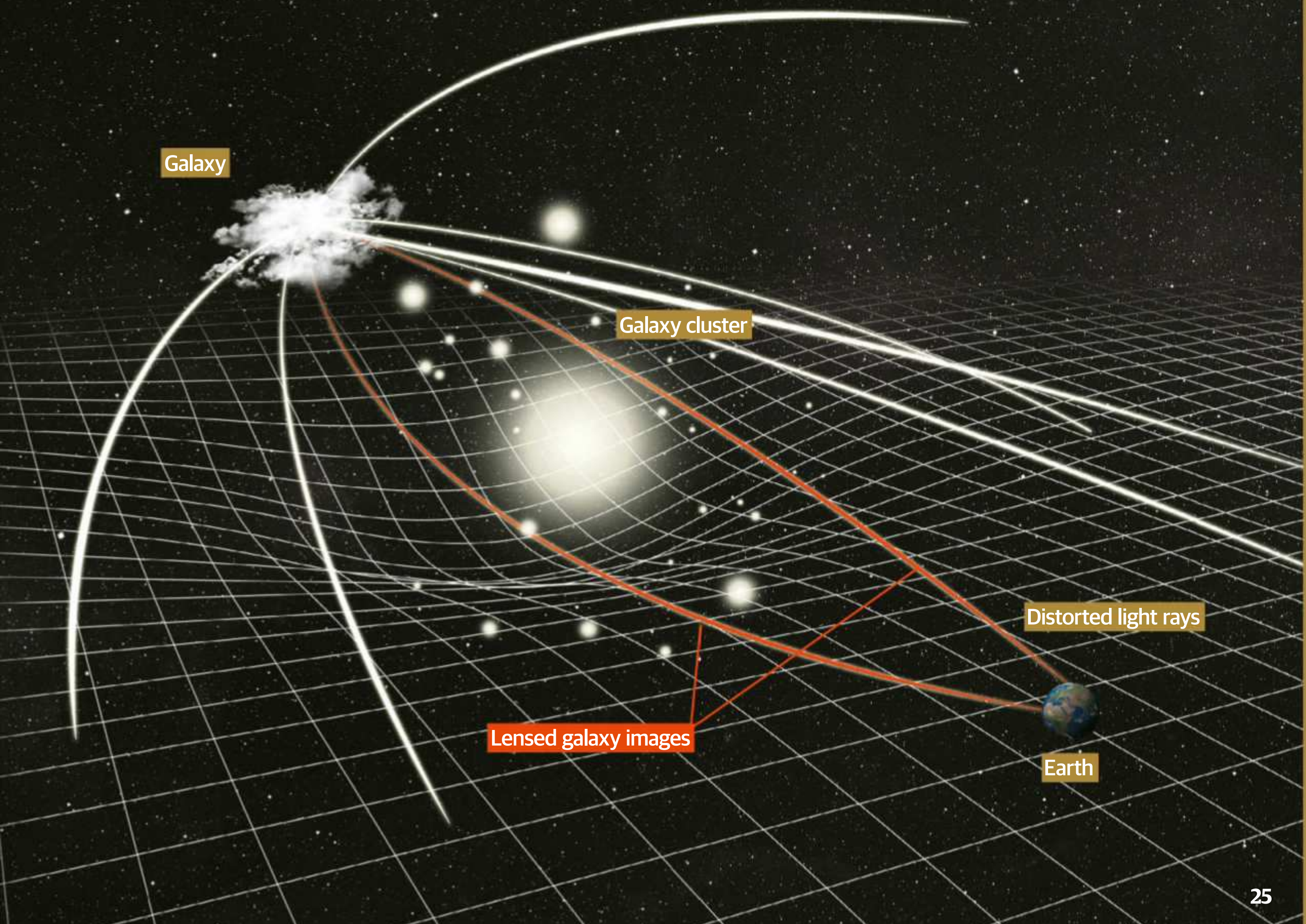
Prof Stephen Hawking

Hawking theory #4

THEORY PROVEN? YES

Hawking energy

Hawking energy is a possible definition of mass in general relativity - Einstein's framework doesn't supply a single definition of mass, but has several which become applicable under different circumstances. Hawking energy has to do with measuring how rays of light bend around a region of space which has a mass you want to define, and once again dissolves into a huge number of equations and symbols. It's an important tool for theoretical physicists, but a bit baffling to the rest of us.



In 2007, Hawking experienced some four minutes of weightlessness in a modified Boeing jet

Hawking's CV in brief

2009-2018
Director of research, Cambridge University Department of Applied Mathematics and Theoretical Physics
Published more books; inspired a Hollywood movie; held a party for time travellers; received Presidential Medal of Freedom, Russian Special Fundamental Physics Prize, and honorary doctorate from Imperial College London.

1979-2009
Lucasian Professor of Mathematics at the University of Cambridge
Pushed boundaries of knowledge of black holes and the beginning of the universe. Published many books, including a ten-million seller and awarded the Copley medal.

1975-1979
Reader in gravitational physics, professor of gravitational physics, Gonville & Caius College, Cambridge
Published first book. Won Eddington, Hughes, Albert Einstein and Pius XI medals, plus the Dannie Heineman Prize and the Maxwell Prize. Honorary doctorate from University of Oxford.

1969-1975
Fellowship for distinction in science, Gonville & Caius College
A post created specially for him. Proposed laws of black hole mechanics. Discovered Hawking radiation.

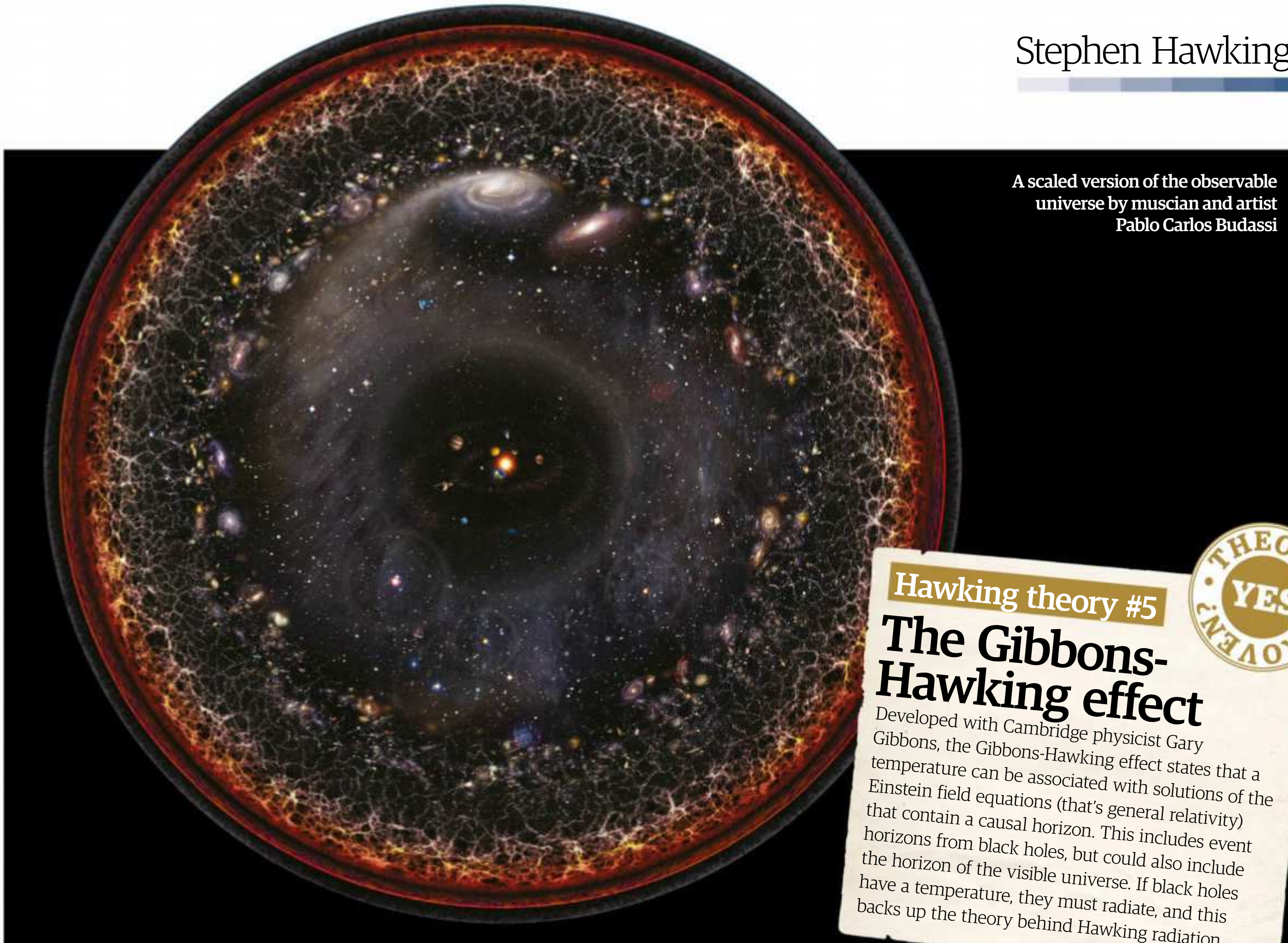
1965-1969
Research fellow, Gonville & Caius College
Extended the concepts of the singularity theorem explored in PhD thesis, explored the idea that the universe may have begun as a singularity.

plain sailing. Early copies of the book, including those sent out to publications for review, were riddled with errors, particularly in the labelling of photos and diagrams. The entire first printing was recalled and pulped, leading Hawking to quip that any surviving copies must be worth quite a lot of money. After an intense period of re-editing and checking, the book was released on April fool's day, and went on to spend a record-breaking 237 weeks on *The Times* best-seller list. While many media reviews concentrated on how remarkable it was that a man with motor neurone disease could have written such a book, Hawking was flattered by one that compared it to Robert M. Pirsig's *Zen and the Art of Motorcycle Maintenance*, writing, "I hope that, like *Zen*, it gives people the feeling that they need not be cut off from the great intellectual and philosophical questions."

In the Queen's 1989 Birthday Honours, Hawking added the Order of the Companions of Honour to his CBE. The order is awarded for "having a major contribution to the arts, science, medicine or government lasting over a long period of time," but he turned down a knighthood because he "does not like titles" according to *The Telegraph*. He has also received 13 honorary degrees, the Paul Dirac medal (1987) and the Wolf Prize – the last one jointly with Penrose.

The books didn't stop coming, and neither did the bets. Kip Thorne, Hawking's friend from Caltech,

An image of Hawking is projected onto Cambridge University during its 800th anniversary light show



A scaled version of the observable universe by muscian and artist Pablo Carlos Budassi

Hawking theory #5

The Gibbons-Hawking effect

Developed with Cambridge physicist Gary Gibbons, the Gibbons-Hawking effect states that a temperature can be associated with solutions of the Einstein field equations (that's general relativity) that contain a causal horizon. This includes event horizons from black holes, but could also include the horizon of the visible universe. If black holes have a temperature, they must radiate, and this backs up the theory behind Hawking radiation.

was often his accomplice, and in 1991 he bet Thorne and John Preskill (also of Caltech) that Penrose was correct that singularities could not exist without an event horizon. He would concede this bet in 1997, then change his mind and replace the wager with one that had further conditions attached. Thorne also planted the idea in Hawking's mind that it might be possible to travel into the past through wormholes, and Hawking began investigating whether this was possible. It was a tricky area of research, however, because it was seen as a joke by many. "In physics circles, there are only a few of us foolhardy enough to work on a subject that some consider unserious or politically incorrect," wrote Hawking. "So we disguise our focus by using technical terms, such as 'particle histories that are closed', that are code for time travel."

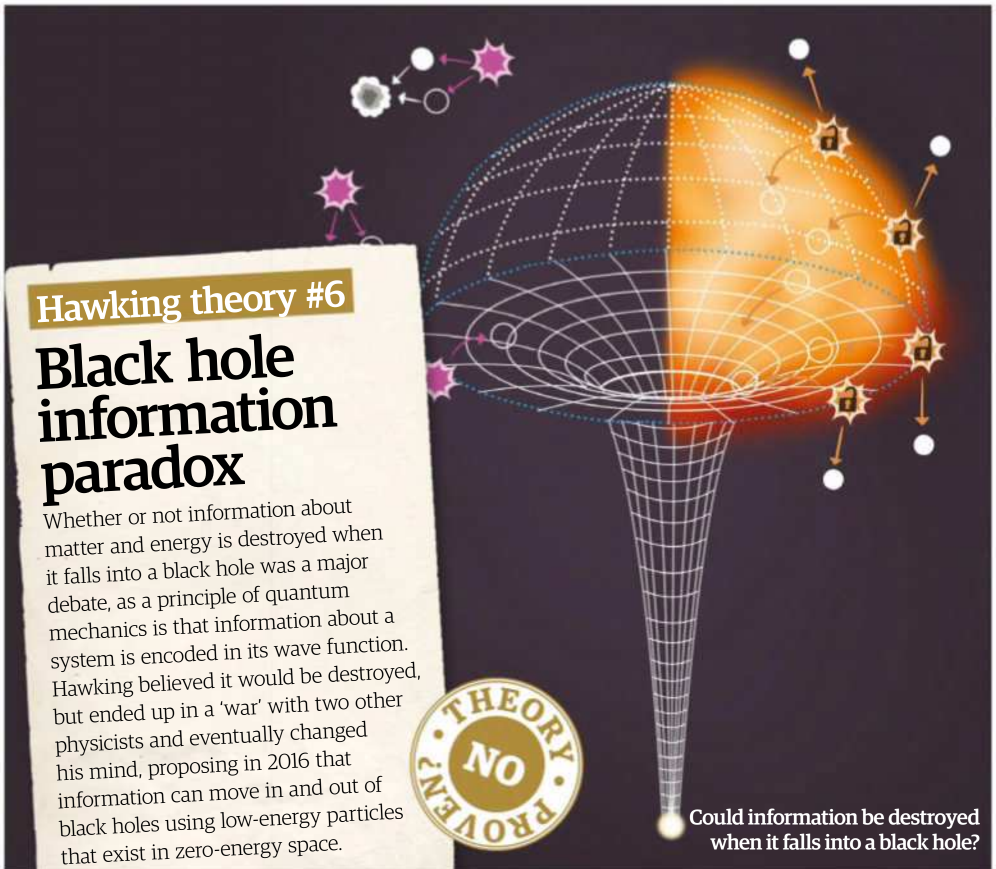
Wormholes, which are yet to be proven to exist, would be useful for rapid space travel as well as popping back in time, and Hawking boiled the question down to whether space-time would "admit time-like curves that return to their starting point again and again." Many solutions to Einstein's equations suggest not, although the work of Kurt Gödel does provide a way around this. Hawking concluded that such closed space-time curves do not naturally occur in our universe, but that an advanced future civilisation could potentially build a time machine and come back to visit us. In 2009, to find out whether he was right, Hawking threw a party for time travellers with champagne, but sent the out invitations after it was over. Only people who could travel back in time would know to come.

"Thorne planted the idea in Hawking's mind that it might be possible to travel into the past"

Hawking's student: Fay Dowker

"His many awards, prizes and honours don't capture the magic that occurred around him"

"Stephen was my teacher, mentor and friend. I, like many who knew and loved him, had come to think of him as immortal, and our sorrow is tinged with a feeling of disbelief that he is no longer here. Robert, Lucy, Tim, members of the Hawking family, friends and carers of Stephen: it has been said, 'The arc of the moral universe is long, but it bends towards justice'. Stephen, in his life, worked to make it so. We can also say, 'The arc of the history of science is long, but it bends towards unity'. Stephen's place in that great history is eternal. Stephen shared his work and his zest for the fundamental questions it addressed with wide audiences. He inspired people with the excitement and importance of pure scientific enquiry and was admired and revered for his devotion, as a scholar, to the pursuit of knowledge. This high regard was demonstrated wherever in the world he gave a public lecture: the auditorium was always packed, the atmosphere electric and the applause thunderous."



Could information be destroyed when it falls into a black hole?

Hawking theory #6

Black hole information paradox

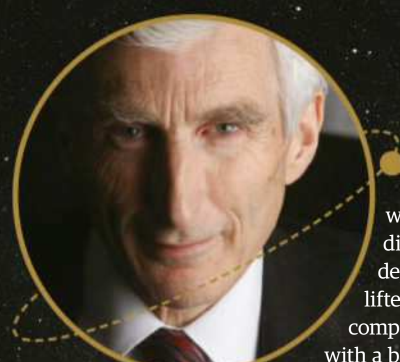
Whether or not information about matter and energy is destroyed when it falls into a black hole was a major debate, as a principle of quantum mechanics is that information about a system is encoded in its wave function. Hawking believed it would be destroyed, but ended up in a 'war' with two other physicists and eventually changed his mind, proposing in 2016 that information can move in and out of black holes using low-energy particles that exist in zero-energy space.

Sadly no one came, and history does not record what happened to all the food, but another attempt was made to catch out time travellers living among us – the ballot for tickets to Hawking's memorial service in 2018 allowed would-be attendees to input a date of birth up to 2038. Hawking was resigned to the fact, however, that time traveller's weren't going to crash his party. "I don't think time travel will ever be possible," he wrote. "If it were, we would have been overrun by tourists from the future by now."

Through the 1990s and 2000s Hawking continued his work on black holes. Hawking radiation, the mechanism through which black holes could evaporate, was impossible under general relativity unless the mass-energy it carried came from somewhere outside the event horizon. This, however, contradicted quantum mechanics. One of the theories needed to change to account for this contradiction, and this led to another bet between the trio of Hawking, Thorne and Preskill over which was correct. The winner would receive an encyclopedia. The bet, placed in 1997, was lost in 2004 when Hawking conceded that event horizons could fluctuate, leaking energy and information that had fallen into the hole earlier, although it would be useless, publishing a paper on the subject in 2005. He bought Preskill a baseball encyclopedia, but joked that he should have burned it first to match the unreadable information found in Hawking radiation. He would go on to call this debate his "biggest blunder".

Fellow Cambridge alumni: Lord Martin Rees

"He was always sensitive to the misfortunes of others"



"[When I met] Hawking, he had recently been diagnosed with a degenerative disease and it was thought that he might not survive long enough to finish his degree. It was soon after I enrolled as a graduate at Cambridge University in 1964. [Hawking] was unsteady on his feet and spoke with great difficulty. Amazingly, he lived on to the age of 76. Even mere survival would have been a medical marvel, but of course he didn't just survive; he became one of the most famous scientists in the world. Astronomers are used to large numbers, but few could be large as the odds I'd have given, back in 1963 when Stephen received his 'death sentence', against witnessing this uniquely inspiring crescendo of achievement sustained for more than 50 years. Few, if any, of Einstein's successors have done more to deepen our insights into gravity, space and time.

"He was, by all accounts, a 'laid back' undergraduate, but his brilliance nonetheless earned him a first-class degree in physics, and an 'entry ticket' to a research career. Within a few years of the onset of his disease he was wheelchair-bound, and his speech was an indistinct croak that could only be interpreted by those who knew him.

"Why did he become such a 'cult figure'? The concept of an imprisoned mind roaming the cosmos plainly grabbed people's imagination. If he had achieved equal distinction in genetics rather than cosmology, his triumph of intellect against adversity probably wouldn't have achieved the same resonance with a worldwide public.

"Stephen was far from being the archetype unworldly or nerdish scientist – his personality remained amazingly unwarped by his frustrations and handicaps. As well as his extensive travels, he enjoyed trips to theatre or opera. He had robust common sense, and was ready to express forceful political opinions. However, a downside of his iconic status was that his comments attracted exaggerated attention even on topics where he had no special expertise – for instance philosophy, or the dangers from aliens or from intelligent machines.

"But there was absolutely no gainsaying his lifelong commitment to campaigns for the disabled, and just in the last few months in support of the NHS – to which he acknowledged he owed so much. He was always, at the personal level, sensitive to the misfortunes of others. He recorded that, when in hospital soon after his illness was first diagnosed, his depression was lifted when he compared his lot with a boy in the next bed who was dying of leukaemia.

"Tragedy struck Stephen Hawking when he was only 21. He was diagnosed with a deadly disease, and his expectations dropped to zero. He himself said that everything that happened since then was a bonus. And what a triumph his life has been. His name will live in the annals of science, millions have had their cosmic horizons widened by his best-selling books and even more around the world have been inspired by a unique example of achievement against all the odds – a manifestation of amazing willpower and determination."

Hawking in popular culture

The Simpsons

Episode: They Saved Lisa's Brain

The first episode of *The Simpsons* in which Hawking appeared, the 22nd episode of the cartoon's tenth season features Lisa Simpson being invited to join the Springfield chapter of Mensa. Director Pete Michels and writer Matt Selman wanted the theoretical physicist to guest-star as himself since 'they needed someone who would be smarter than all of Springfield's Mensa members and because he was a fan of the show'.

Star Trek: The Next Generation

Episode: Descent

The only person to date to have played himself on Star Trek, Hawking appeared as his own holographic counterpart in 1993 playing poker with the likes of Albert Einstein and Isaac Newton. During filming of the episode, Hawking was taken on a tour of the engineering set.

The Theory of Everything

Release date: 2 January 2015 (United Kingdom)

A British biographical romantic drama film set at Cambridge University, *The Theory of Everything* tells the story of Hawking's life. The film, in which actor Eddie Redmayne plays the physicist, was adapted from the memoir *Travelling to Infinity: My Life with Stephen* by his former spouse Jane Hawking.

Hawking

Release date: 13 April 2004 (United Kingdom)

In the first ever portrayal of Hawking on screen, Benedict Cumberbatch stars as the physicist during his early years as a PhD student at Cambridge. The BBC television film was nominated for Best Single Drama in the BAFTA TV Awards in 2005.

The Big Bang Theory

Episode: The Hawking Excitation

Hawking appeared in the 108th episode of the American sitcom where main character Sheldon Cooper is keen to meet his idol. In the episode, Hawking is given Sheldon's research paper on the Higgs Boson particle, where the character believes that a boson is at the centre of a black hole accelerating backwards through time.

Futurama

Episodes: Anthology of Interest I, Crimes of the Hot, The Beast with a Billion Backs, Reincarnation

Hawking featured as himself, lending his voice in several episodes in the American animated science-fiction comedy series made by *The Simpsons* creator Matt Groening.

Hawking's student: Ian Moss

"He was the definition of a genius"

"This was a time when he could still speak, before his voice synthesiser, and only students could understand what he was saying.

"What impressed me about Stephen was that he was absolutely brilliant. Some people are very clever and you see their work and you think, 'well, if I worked really hard on that project maybe I could have done that myself'. Then there are people like Stephen, and you see his breakthroughs and you think, 'there's no way I would have thought of that if I'd spent all my life thinking on that project'."

Another example of Hawking not quite getting everything right came in 2002, when he engaged in a debate with Peter Higgs over whether the Higgs boson – an elementary particle predicted by the standard model that gives other particles mass – would ever be discovered. Higgs criticised Hawking soundly, complaining that his celebrity status "gives him instant credibility that others do not have". Higgs was vindicated in 2012 when the Higgs boson was discovered at CERN, after which Hawking suggested he should win the Nobel prize in physics, which he did the next year with François Englert.

Hawking retired from the Lucasian professorship in 2009 – as stipulated in Cambridge University's regulations – having held it for 30 years, and moved on to be director of research at the Cambridge University Department of Applied Mathematics and Theoretical Physics. He continued to work through his 60s and 70s, ranging over topics such as the future of humanity, manned spaceflight, the dangers of AI and attempts to discover the unified theory, first touched upon in *A Brief History of Time*, that will bring together general relativity and quantum mechanics. He also appeared in many TV series, had a movie made about his early life and received the Presidential Medal of Freedom, America's highest civilian honour, from Barack Obama in 2009. His final paper, on cosmic inflation, was published in May 2018 – six weeks after his death in March 2018.

15 years before his death, he had already decided on his epitaph: the Bekenstein-Hawking entropy equation, or a series of numbers and letters that define Hawking radiation. "When I was 21 and contracted ALS, I felt it was very unfair," he wrote. "But now, 50 years later, I can be quietly satisfied with my life. My disability has not been a serious handicap in my scientific work. In fact, in some ways I guess it has been an asset: I haven't had to lecture or teach undergraduates, and I haven't had to sit in on tedious and time-consuming committees. I became possibly the best-known scientist in the world. This is partly because scientists, apart from Einstein, are not widely known rock stars, and partly because I fit the stereotype of a disabled genius. I can't disguise myself with a wig and dark glasses – the wheelchair gives me away."

Hawking's ashes were interred in the nave of Westminster Abbey on 15 June 2018 alongside the grave of his predecessor in both thought and professorship, Isaac Newton. His work lives on, however, and a newborn black hole in the constellation Ophiuchus, GRB180316A, has been dedicated to him. Neither can be expected to evaporate any time soon.

> "My disability has not been a serious handicap in my work. In some ways I guess it has been an asset" **Prof Stephen Hawking**

Hawking's final theory

The universe is a hologram

It's generally believed that for a tiny fraction of a second after the Big Bang, the cosmos expanded rapidly before it settled into its current state, in what is known as inflation. On a grander scale, however, some believe that this expansion goes on forever, creating a multiverse – a theory that Hawking has never been particularly fond of.

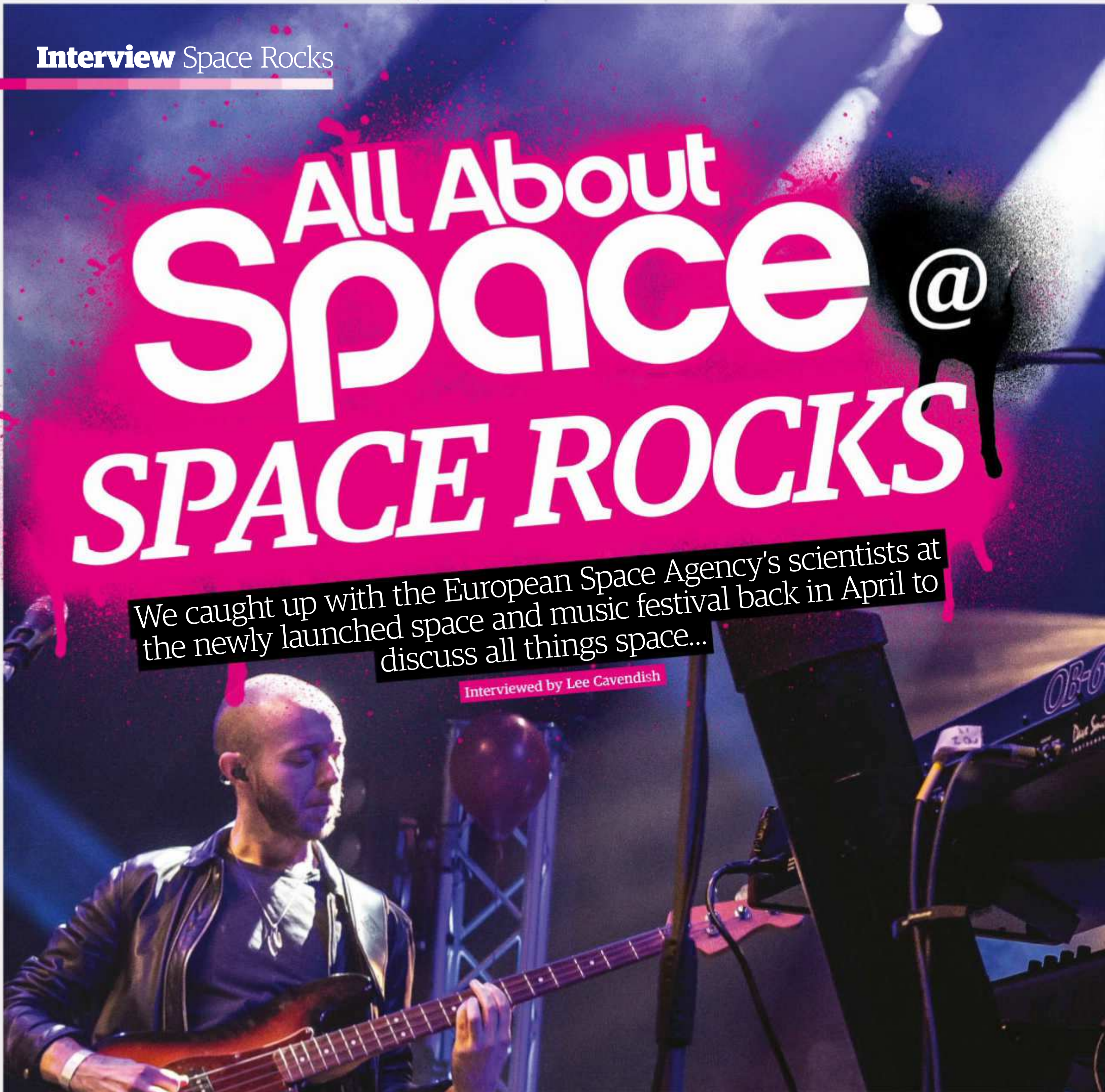
Instead he, alongside Belgian colleague Professor Thomas Hertog, has extended the notion of a holographic reality in order to explain how the universe came into existence after the Big Bang. In this theory it's suspected that three-dimensional reality is an illusion and that the solid world around us – including the dimension of time – is projected from the information on a flat two-dimensional cosmos. With this in mind, Hawking believed that the universe arose holographically from an unknowable state outside the Big Bang.

Hawking suspected that the cosmos is holographic

All About Space @ SPACE ROCKS

We caught up with the European Space Agency's scientists at the newly launched space and music festival back in April to discuss all things space…

Interviewed by Lee Cavendish



Lonely Robot perform at the event under a model of Rosetta

Tim Peake recalls his mission into space

INTERVIEW BIO

Dr Beth Healey

Beth is a medical doctor who was part of a team that spent a year at the European Space Agency's Concordia Research Station in Antarctica as a Research MD. This year was spent analysing the physical and psychological effects of isolation in the most remote and extreme region of the world.

How did you come to get involved in the Concordia experiment?

I had a lot of experience working in extreme and remote environments, mainly as medical and logistical support team work. It was really coming from more of a polar background, I guess, that I initially got involved with the European Space Agency and the job I had [in Concordia], and then I learned the space stuff afterwards.

What was the most satisfying part of working from Antarctica?

Well, I guess the thing I find most satisfying is to look at how we can use the research that we're doing for space and for life back on Earth, as well as the clinical applications within healthcare. We really are learning from pushing ourselves both physiologically and psychologically in these extreme environments.

It's a lot like how we're using altitude studies to help inform us about hypoxia and low-oxygen levels that we see in people in intensive care. Space technology, and the research we're doing for space flight, is really an extension of that, which is why I find it so exciting. Because not only is it helping us with the exploration aspect, but it's also helping everybody, from remote villages to disaster relief to providing medical care to people that can't current access it.

What other space analogues are there? Can any member of the general public become involved in them?

Yes, absolutely. So there are all these different analogue platforms. You have things like the Mars Desert Research Station, and that's certainly a platform that anyone can use. It's a much shorter time period, but you can go and use that platform and carry out your own research projects and get an experience and a taster into what analogue programmes are about.

What aspects of long-duration human space exploration do you think need more attention in terms of research, whether it's technological, physiological or psychological?

I guess it's the overall picture. I think the biggest challenge will be the psychological challenge, but there are also a lot of physiological challenges that we need to overcome. For example the radiation and the lower pressure we'll be experiencing. That's why we're doing research into the effects of the sleep-wake cycle – so not having the Sun in the same way we do back on Earth.

These are all challenges that we are going to have to overcome. Then, of course, with there being a small group in such a closed, confined environment, [this] will pose the biggest challenge of all. But I really do believe that all the research we're doing and developing the training that astronauts have before they head to space in order to overcome some of these challenges will make going to Mars a reality.

Would you ever become an astronaut?

I would love to be an astronaut, for sure. Actually, to be honest, it wasn't something I grew up wanting to be. But it's certainly something that, since working for ESA and that experience in Antarctica and just meeting all the astronauts as well, it suddenly made it more tangible.

I think the idea when I was growing up, the idea of being an astronaut, was just so far removed from my life in the countryside back in rural Hereford [United Kingdom]. It wasn't ever something I considered, but I think now, yeah, for sure! Give me a ticket and I'll be there.

L-R: Dallas Campbell, Maggie Lieu, Tim Peake, Beth Healey & Matt Taylor

INTERVIEW BIO

Dr Matt Taylor

Matt is the project scientist of the Rosetta mission which successfully travelled to, and landed the Philae lander on Comet 67P/Churyumov-Gerasimenko. He obtained his PhD in Space Physics from the University of Liverpool and his main scientific interest is research on space plasmas.

Where are you at in the data processing from the Rosetta mission?
Rosetta ended operations in September 2016 and since then we've been making sure that we got all of the data down [to Earth]. We're just making sure that the set of calibrations has been done well enough to allow us to put it in the archives.

We only really analysed about five to 10 per cent of the data during the mission operations, because it was so intense. Now the teams are focusing on doing the science, and that's what's coming out now.

Where can we can find the new data?
Well, all the data is basically there in the ESA archives, up to about six months from the end of the mission. One would have expected some of it to be out earlier, but for various reasons there is some data that's been there for ages. Other data is still being worked on a bit more as it's been harder to calibrate. It's there for everyone to use. Go have a look!

What was it like when you actually realised that the Philae lander had landed successfully on Comet 67P?
For me, it was all about that it was going to work. There was no question of it not working, because we had the best team in the world to do this mission – to make that happen. There was relief, but I was swept up in the operational aspects of going: 'All right, this is going to happen. We need to do this. We need to look at this.' Then we were already planning what we were going to do with the Rosetta mission immediately afterwards, and up to four to six months.

So during operations there were things happening all the time, but you were also thinking ahead. I think only after the mission operations ended I was able to rein back and go, 'OK'. That was a recovering period for me – put it that way. Everyone was kind of taking stock of what just happened.

What was the importance of studying a comet up close?
Because it is a fantastically diverse object. It had this very significant bilobed nature not uncommon in comets – but it really was striking with this duck shape. But with regards to the surface features, and the material we found, it kind of has all the bits of all the comets we've ever looked at or observed, and they were all in one comet that we were able to study.

The reason we study them? Because we look at them as treasure chests of what the Solar System was like at its beginning. In fact, some of the stuff we were looking at with Rosetta, for instance the oxygen molecules we discovered on the comet, that was a surprise to us. Because it's there, it constrains how we believe the comet actually formed, so it actually says something about the protostellar cloud. It could be that there is material in that comet that predates the formation of the Sun. So just from studying this funny duck-shaped black object – to me is mind-blowing – that you can make that connection to the entire Solar System's formation. That's why.

Space Rocks attendees gather around the European Space Agency's stand

Space Rocks attendees meet astronaut Tim Peake

INTERVIEW BIO

Dr Maggie Lieu

Maggie is a research fellow at ESA and is heavily involved in the Euclid mission that will attempt the answer the elusive questions surrounding dark matter and dark energy. She obtained her PhD from the University of Birmingham and focuses on weak gravitational lensing and X-ray observables.

Tell us more about ESA's Euclid mission.
ESA's Euclid mission is a 1.2-metre telescope and it's meant to go into space at L2 – one of the Lagrangian points, where the orbit is going to be super stable and doesn't need to use much fuel.

It [Euclid] is an optical/infrared telescope. Its optical instruments will measure the shape of galaxies very, very accurately, so we can do gravitational lensing measurements. Infrared will help see the very, very far away galaxies.

What is its current status?
At the moment Euclid is due to launch in 2021, but only time will tell if it does or not as space missions tend to be delayed.

What are the advantages of studying dark matter and dark energy in space?
With dark matter, the only way we can directly measure it at the moment is through gravitational lensing. This is when any foreground dark matter, or any foreground massive object with a large gravitational effect distorts the shape of distant galaxies.

From Earth we have to look at the galaxies through the atmosphere, clouds and turbulence in the atmosphere, so it makes it more difficult to get the shapes of these galaxies really accurate.

What drew you to this area of research?
When I was in university I did a course on cosmology and I was interested in how the universe works. [When learning about] dark matter and dark energy, I was like 'oh my god, I don't understand them. I must figure it out! They are the biggest components of our universe, and we don't know what they are or their nature!'

Do you think there should be more of a push towards more missions and

Aerolite Meteorites' Geoff Notkin and Nick Howes

experiments dedicated to studying dark matter and dark energy?
So there are a lot of missions and experiments focused on dark matter already. There are a lot of Earth-based experiments, like neutrino detection experiments. At CERN [The European Organisation for Nuclear Research] they were looking for dark matter. There is a lot [of dark matter and energy research] already, but we haven't found it, and that's even more baffling! So ultimately yes, I think so.

What do love most about working for ESA?
ESA is a great family to work for. I'm in ESAC [European Space Astronomy Centre] in Madrid, Spain. Where I work, there are about ten scientists full time. Everyone else is like mission design, mission operations, there are a lot of engineers, mission planning and things like that.

It's a really good insight into how our mission works. I mean, a lot of scientists in universities just take the data and just use it. They don't know where it comes from or whatever. But I'm working directly with people who are launching the rockets that the science payloads go on. I'm working with people who are controlling these things and all sorts of things. The entire staff of a science mission, I interact with those people and it's really good to get that insight.

INTERVIEW BIO

Professor Mark McCaughrean
Mark is the senior science advisor in the Directorate of Science and Robotic Exploration department at ESA. Mark has worked on many prestigious space science and exploration missions including the Hubble Space Telescope, Rosetta and the James Webb Space Telescope.

You've had the pleasure of working on many space exploration and space science missions. Do you have one you're particularly fond of?
I think that's the same question as which is your favourite child. The one I have been involved with the longest is Hubble.

I was involved with Hubble when it first launched. I was working on the Hubble Space Telescope for future instrumentation in 1990 and, as people know, Hubble had a problem with its main mirror called 'spherical aberration'. In order to repair it they took money away from the future parts of Hubble, so I lost my job at that point. I hadn't done anything wrong, but they needed the money, so many of us got fired at that point.

Then I moved back to Europe, and not too long after that I got involved in the James Webb Space Telescope mission in 1998, and I've been involved ever since. So I'm on what's called the 'Science Working Group', which means that we're the people who are actually trying to plan the science of James Webb.

So that's my science [favourite], but if there's an emotional favourite, it has to be Rosetta. It changed everything for us at ESA by connecting with people so much around the world.

Going back to Hubble, is there a particular scientific result that came from that mission which stands out?
Well, I work in star formation. I work on the birth of stars and planets in the Milky Way. In 1996 I was very involved in a project photographing the Orion Nebula with Hubble. The Orion Nebula is very bright in emission lines oxygen, sulfur and hydrogen, and it makes for such a bright background that we could see, for the very first time, that some stars had black ovals around them. Those black ovals are the discs in which stars and planets are made. That was the result I published with Bob O'Dell, who had worked on Hubble for many years.

But the interesting story there is that when I was uploading our images to the release site - back in those days, the press release site was just an FTP archive; they gave you the password, you go in and upload your stuff. Being a bit nosey, I thought there was some interesting other directories. So when I was sitting in my office on a Saturday afternoon, I thought 'I wonder what else is in there that might be cool'.

I clicked on one that said M16 - M16 is the famous Eagle Nebula - and I thought 'well, I wonder what Hubble sees in there'. I saw what are now probably the most iconic pictures taken with the Hubble Space Telescope: the 'Pillars of Creation'. I saw them in my office on a Saturday afternoon and just downloaded them, which I probably shouldn't have done. But I looked at them and I just thought they were stunning.

Is there a mission coming up in the future you're particularly looking forward to?
A future mission that I'd really like us to do is to go to Titan [Saturn's largest moon] again. We landed on Titan in 2005 with the Huygens probe. We crunched down on this sort of crème-caramel surface, [Huygens] lasted a couple of hours there. But to go and float something in the oceans and seas of Titan, and maybe even put submarines down to the bottom, I think that it would be an incredibly cool thing. Dragonfly drones are also being talked about, so I think there's some really interesting things to be done there.

But the other one that really excites me is our LISA [Laser Interferometer Space Antenna] mission, the gravitational wave observatory. Now we've proven we have the technology for gravitational-wave detection in space, we can now build the full observatory. That would be mind-blowing.

So when can we expect to see LISA in space then?
Well, in principle LISA should be there in 2034, if we take the natural sequence. But we're now proposing to bring it forward by four years, so that we can fly it at the same time as our other next big observatory ATHENA [Advanced Telescope for High Energy Astrophysics], which is an X-ray observatory.

So we're proposing it at the end of next year in order to be able to fly them both at the same time. That would be great, but either way I will be retired by 2030, so I'll be watching it from my deckchair in the background.

DIY SPACE PROJECTS

Have some spare time on your hands? Check out these activities that can be done at home - without having to be an engineer

You don't have to be a space agency engineer to combine space sciences and craftsmanship. These projects produce some amazing results with dedication, some elbow grease and a fair amount of free time. Labelled either 'easy' or 'expert', these projects will be sure to keep you busy, especially the 'expert' ones. Each project is excellent in combining a love for astronomy and space exploration with a hands-on approach. You can go from making your own model of the famous Saturn V rocket, the rocket that launched the first humans to the Moon in 1969, to firing a powerful laser at the Moon to confirm how far away it is.

None of these projects can be done with items just lying around the house, unlike an episode of *Art Attack*, so you'll need to make checklist for your desired activity. Everyone loves a challenge, and the harder projects are always the more rewarding. If you follow these guides, along with our recommended 'For more information' sites, you can create a masterpiece.

#1 Make your own telescope

The simplest option. This DIY telescope can be is quicker and easier to make than the other projects. With a simple selection of materials and tools you can create your own sliding telescope, probably best suited as an educational tool.

Although it can't provide a decent enough focus to delve into the true sights of the night sky, it is an excellent educational experience for a youngster or beginner. The general workings of a reflector telescope can be learnt, such as light focusing, and if this project takes your fancy then you could try a more advanced version.

For more information, watch Canada Science and Technology Museum's video titled 'How to Build a Telescope' at: youtube.com/watch?v=uZeF1KETaU4

1 Materials checklist

The list of materials and tools needed for this project is simple, containing mostly household items. In order to make your own telescope you must have a large piece of black Bristol board, a glue gun, a stapler, black electrical tape, a pair of scissors, a cardboard tube and two magnifying glasses – ideally one should be bigger than the other.

2 Assembling the tubes

Cut three black Bristol board sheets – two to fit around the cardboard tube and one twice the length. Glue the smaller sheets around and within the cardboard tube, and place the longer sheet in the tube, stapled at its ends, glued and wrapped in electrical tape to secure it, while still allowing it to slide in and out properly.

3 Fix the lenses

The first, larger lens should be glued to the top of the cardboard tube and secured with electrical tape. At the other end of the telescope the second lens should be fixed to the end of the slider tube, similar to the first lens. The sliding focus lens will concentrate the light from more distant objects to suit your eyes.

4 Finishing touches

Once the telescope is complete some final decorative touches can be added. Taking some crayons, or coloured chalk, you can draw some constellations over your telescope, but this is dependant on your personal preference. Now everything is in order to give your new telescope a test run and see what sights are at your disposal.

#2 Building a Mission Control desk

The household 'Mission Control desk' is a great way to get more involved in space. Not only is it visually stimulating, but there are buttons and authentic sounds. It can also be folded away and used as a normal desk for when work needs to be done. This project requires a fine craftsman and access to machinery such as drills, saws and sanders.

This project requires a lot of woodwork and wiring, but upon completion it will be a great representation of what it's like being at NASA's Mission Control Centre, experiencing what real mission control personnel have gone through during a mission.

For more information, please check out Make:'s extensive how-to guide titled 'How to Build a Mission Control desk' at makezine.com/projects/mission-control-desk/

1 Careful planning

Planning is of the utmost importance when building a control centre replica. You need to weigh up how much room you have to work with, but also how much time and money you wish to invest in this. Depending on the size of your desired desk, the control panel can be designed containing displays, speakers and controls

2 Construct and wire

This is going to be the most intense section of the project, as it requires the actual construction of the control centre as well as the cutting out, priming, painting and printing of the individual panels. Getting into the more electronic side, the switches and LEDs must be wired safely as well.

"This rocket is the vessel that launched humanity into the space age"

© Revell; Nicholas Forder; Make/YouTube

#3 Building your own Saturn V Model Rocket

EASY

The rocket that took the first humans to the surface of the Moon, NASA's Saturn V rocket, is a testament to human endeavour and space exploration. This rocket is the vessel that launched humanity into the space age, and now you have the opportunity to celebrate this by building your own 1:144 model.

Revell, a well-known manufacturer of scale models, has a model of the stupendous Saturn V available for £26.30 (€29.99). All else that is needed to complete this task is glue, paint, paintbrushes and a fine hand. What comes included is the full model kit, including all the separate stages and a launch pad, a booklet of building instructions and decals. For a smooth and safe assembly, please be sure to read through the instruction manual before tackling the task.

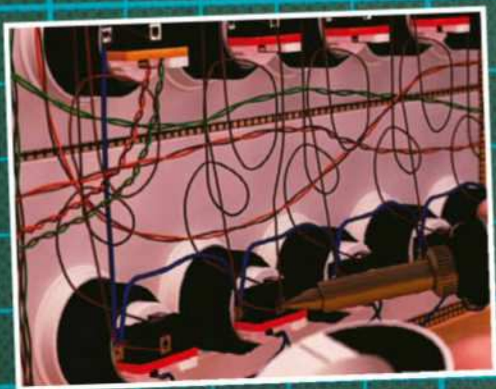
A lot of gluing is involved in this model, so the best way to kick-start the project would be to go through the building manual and deduce which minor sections, such as the thrusters, need gluing and need to dry before they can be added to the main structure. The best way to start off is construction of the first stage and its five thruster nozzles. On the actual Saturn V used in the 1960s and 1970s, these thrusters collectively produced an astounding 33,400 kiloNewtons of pure power.

Next is the assembly of the second stage, equipped with its own set of five thruster nozzles, and the third stage with a singular thruster nozzle. There is more to the model than just its stages, as it also includes a detailed lunar module, the service module, the command module, a emergency rescue rocket fit to the nose of the rocket and finally three figurines, which add a real sense of scale. All three stages and the different modules are detachable, which means this model can serve as a good educational tool as well.

After everything is glued and dried, you can start paining. Revell also sell a good-quality series of paints and sets of paintbrushes at a reasonable price. According to the manual, 13 different colours are stated as being used – with them naming all 13 colours. The model primarily consists of white and black, so it may be worth stocking up on these two colours so you have enough to finish the model.

After the paint has dried, it is time to add the finishing touches in the form of the decals. These labels can be stuck to their designated place on the model rocket, and you can finally marvel at your 77-centimetre (30-inch) high model of the Saturn V rocket.

© Revell



EXPERT

3 Adding the sounds

Audio files from the Apollo 11 mission can be found online at NASA's Apollo 11 Flight Journal. MP3 files can be downloaded from the website, and they can be edited using a computer program such as 'Audacity'. This stage also requires programming, which will help designate the correct switch to its correct sound.

4 Refining the Mission Control Centre

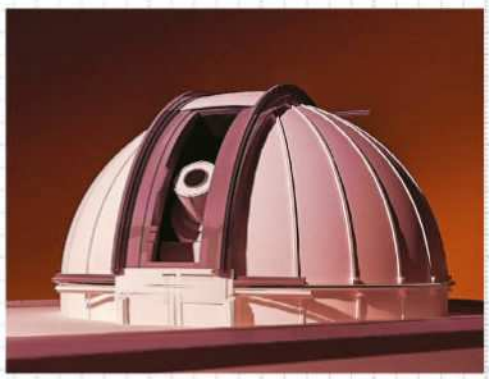
In principle, everything should be in place to have your Mission Control Centre up and running. However, it may not be perfect first time around, so we recommend giving it a 'test run'. From this you can tweak any software and hardware that needs it and make any other improvements as you see fit.

#4 Firing a laser at the Moon

The Moon lies 384,400 kilometres (238,900 miles) away from Earth. How do we know that? Well, during the Apollo missions astronauts placed retroreflectors on the Moon so that powerful lasers can be fired at these mirrors from Earth and be reflected back. By undergoing an experiment such as this one, anyone on Earth can confirm the distance to the Moon using the aforementioned powerful laser and some simple maths.

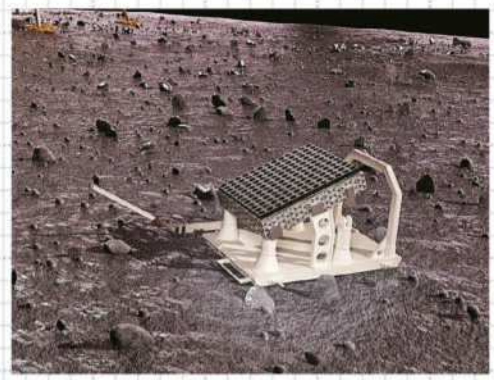
Unfortunately, this is not a project you can conduct with a laser-pointer pen. To do this, you'd need a telescope capable of firing much more powerful photons. It would be worth renting time at a local observatory in order to undergo such an exciting experiment.

EXPERT



1 Finding the observatory

An observatory should have the equipment necessary, and you can get help from an astronomer who has done this before. The experiment will go a lot quicker with fantastic help.



2 Commence firing

With much precision and perseverance, you can start firing the laser through the telescope and at the Moon, aiming for one of the retroreflectors left on the lunar surface.

3 Returning photons

If the alignment between telescope and retroreflector is perfect, then the laser photons will return back to the telescope, go through the optics and hit the sensors.

4 Deducing the distance to the Moon

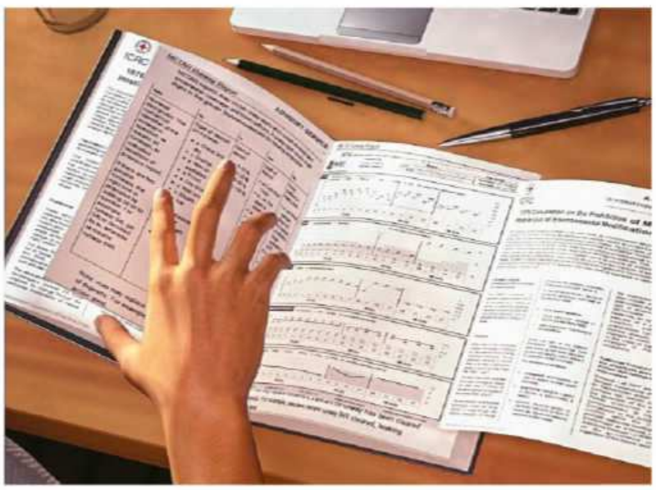
By knowing the time taken for the photon to return, and that the speed of light is constant at three billion metres (186,000 miles) per second, the exact distance to the Moon can be calculated.

#5 Launching a high-altitude balloon

Why would you want to launch a high-altitude balloon? The best answer is that it is the closest you can get to conducting space observations without the launch of a rocket. With plenty of planning and teamwork, this balloon can produce some amazing images while also demonstrating the effects of aerodynamics, physics and other important aspects of science.

Planning is key. Not only does it require a carefully selected selection of instruments, it also requires clearance by local authorities as it could interfere with aircraft. We highly recommend taking great care in the planning to avoid incident.

For more information, check out Tracksoar's fully informative article at: tracksoar.com/a-tutorial-for-launching-your-first-balloon/



1 Checking regulations

As mentioned previously, checking the local regulations and informing the proper authorities about your launch location and time is essential. There are certain requirements for the dimensions and contents of the payload that will need to be taken into account before you launch.

2 Gathering the materials

The essentials are a latex weather balloon, lifting gas and a filler tube, rope to connect the payload, the payload packaging and a parachute. All of these pieces will need to be of good quality to insure maximum protection. The contents of the payload will have to contain a tracker in order to collect the balloon upon landing.

3 Launching the balloon

The launch site must have been chosen as part of the planning process, and you'll need a crew of at least two. We recommend having one person with experience as part of your crew, and someone who is a licensed amateur radio operator if you have an APRS tracker. Once everything is set, you are ready to launch the balloon!

4 On its return

When the balloon has reached high altitudes the payload can finally start getting the amazing snapshots and collecting real scientific data. The average flight time is around three hours, but time will vary depending on the balloon and payload size, among other things. Use the tracker to find your payload once it drops back to Earth.

Giant rockets

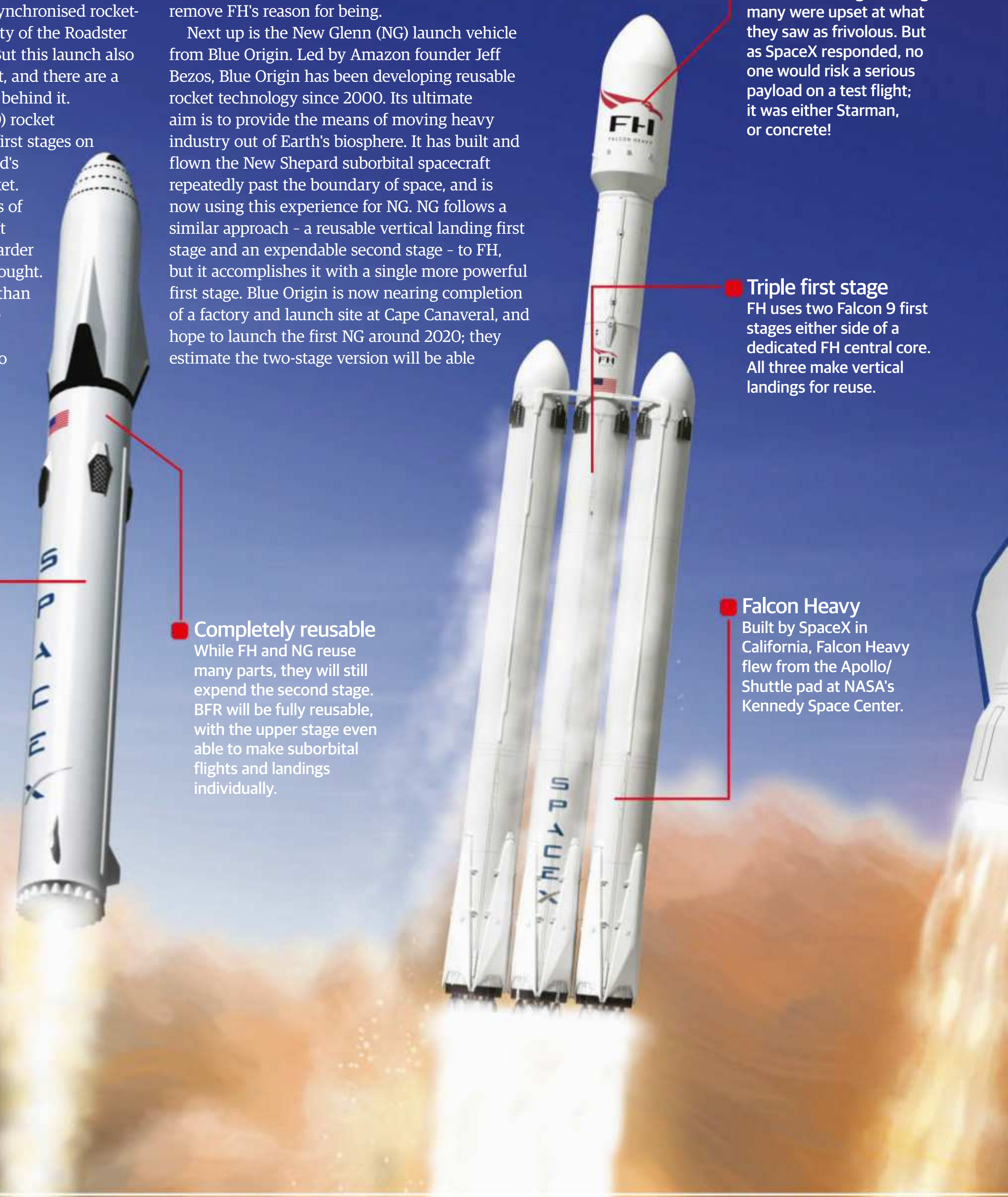
Some 45 years after the last Saturn V flew and the USSR gave up on the N1, a group of rockets are under development that will finally surpass them

When SpaceX launched the Falcon Heavy (FH) for the first time on 6 February 2018 it captivated the world in a way a space launch has not done since that of the first Space Shuttle in 1981. The spectacle of its twin boosters making a synchronised rocket-powered landing and the novelty of the Roadster payload dominated the news. But this launch also opened a new era in spaceflight, and there are a queue of competitors lining up behind it.

FH consists of a Falcon 9 (F9) rocket augmented with two extra F9 first stages on either side, and is now the world's most powerful operational rocket. SpaceX founder Elon Musk says of the creation of Falcon Heavy: "It actually ended up being way harder to do Falcon Heavy than we thought. Really way, way more difficult than we originally thought. We were pretty naive about that."

FH can place 63.8 tonnes into low-Earth orbit, 26.7 tonnes in geostationary orbit or send 16.8 tonnes to Mars. But it is just the first of a group of new giant rockets slated to fly over the next five years, including one that will remove FH's reason for being.

Next up is the New Glenn (NG) launch vehicle from Blue Origin. Led by Amazon founder Jeff Bezos, Blue Origin has been developing reusable rocket technology since 2000. Its ultimate aim is to provide the means of moving heavy industry out of Earth's biosphere. It has built and flown the New Shepard suborbital spacecraft repeatedly past the boundary of space, and is now using this experience for NG. NG follows a similar approach – a reusable vertical landing first stage and an expendable second stage – to FH, but it accomplishes it with a single more powerful first stage. Blue Origin is now nearing completion of a factory and launch site at Cape Canaveral, and hope to launch the first NG around 2020; they estimate the two-stage version will be able



Tesla Roadster
The Tesla Roadster and Starman dummy produced remarkable images, though many were upset at what they saw as frivolous. But as SpaceX responded, no one would risk a serious payload on a test flight; it was either Starman, or concrete!

Triple first stage
FH uses two Falcon 9 first stages either side of a dedicated FH central core. All three make vertical landings for reuse.

BFR
The BFR has been designed to fulfil SpaceX's Mars ambitions. Initially planned to be 12 metres in diameter, it was scaled back to 9 metres to fit existing infrastructure.

Completely reusable
While FH and NG reuse many parts, they will still expend the second stage. BFR will be fully reusable, with the upper stage even able to make suborbital flights and landings individually.

Falcon Heavy
Built by SpaceX in California, Falcon Heavy flew from the Apollo/Shuttle pad at NASA's Kennedy Space Center.

> "It actually ended up being way harder to do Falcon Heavy than we thought" **Elon Musk**

to launch 45 tonnes into low-Earth orbit.

Possibly joining these new space upstarts at the Cape in 2020 will be NASA's congressionally directed blast from the past, the Space Launch System (SLS). The official launch vehicle of NASA's beyond-Earth orbit plans, SLS is the latest descendent of the George W. Bush-directed Constellation program and its Ares V launch vehicle. SLS is an expendable design based on re-purposed Shuttle and Saturn V technology; it will even be throwing away previously reused Shuttle main engines on every launch – reportedly one every year and to cost roughly $1 billion per flight! President Obama briefly managed to cancel it along with Constellation in favour of a more progressive space exploration plan before the congressional representatives of the Shuttle-building states managed to bring it back and compel NASA to follow their specifications. SLS is actually a rocket defined by Congress rather than NASA, but if it does continue to survive Trump's cuts it will be able to send up to 130 tonnes (very expensively) into LEO.

Finally, SpaceX is promising the first flight of its BFR (officially Big Falcon Rocket) in 2022. Initially proposed by Musk in 2016 as part of SpaceX's Mars transport plan as a truly gargantuan 12-metre-diameter, 100-passenger vehicle, BFR was scaled back relatively to a still-gigantic nine-metre-diameter, 4,400-tonne craft in 2017 so it would fit more of SpaceX's existing infrastructure. A 58-metre-tall fully reusable first stage, which SpaceX expects to be able to land back on the launch pad, will propel a 48-metre-tall reusable spaceship (or tanker) into space; where it can be refuelled for missions to the Moon or Mars. SpaceX expects the economies of scale and reuse to enable BFR to replace its entire Falcon/Dragon capsule system. After four decades as a trickle, the race to space is on.

Liquid Oxygen/ Hydrogen
Where FH burns LOX with kerosene, like Saturn V, NG will use liquid hydrogen and LOX like the Space Shuttle. It offers greater performance, but is more difficult to handle.

New Glenn
The two-stage variant stands at 86-metres tall and 7-metres in diameter, which is slightly bigger than FH; it is being developed by Blue Origin in Seattle, but will be built on site at Cape Canaveral.

SLS
The SLS has been designed to continue the use of Space Shuttle technology. It is completely expendable. There are three planned versions of the SLS.

© Adrian Mann

Chris Hadfield & NASA's finest reveal...

"OUR MOST DANGEROUS MISSIONS"

Rigorous training. Meticulous planning. Cutting-edge technology. And still things can go very, very wrong in space

PART 2 OF 3*

So far nobody has ever drifted off into space – and no astronaut has ever been caught napping on the job. But that's because astronauts know the importance of remaining alert during their spacewalks and when carrying out important tasks.

Even so, that doesn't mean everything runs like clockwork. As we saw in our last issue, astronauts who have walked on the Moon have worried they may never come back to Earth. There have also been near-drownings and space shuttles that have sped up when they should have been slowing down.

But there's more. Here, in part two, we look at some further mishaps, as well as the quick thinking and speedy decision making which invariably turned disaster into a very important learning process.

*Catch the final part in issue 80, on sale 19 July

Turn to page 52

Thomas Jones waves while working on the International Space Station in 2001 during one of his three scheduled spacewalks with Robert Curbeam

"Bob was straight on the radio reporting a leak. He was concerned"

Thomas Jones' heart sank when coolant leaked from the Space Station and shot ammonia crystals at partner Robert Curbeam

What happened?

As Thomas Jones and Robert Curbeam were connecting cooling lines on the ISS in order to install the Destiny Laboratory Module, a quick-disconnect value became defective and caused some of the ammonia cooling supply to escape into space. To both of their horror, toxic ammonia crystals coated Curbeam's helmet and suit.

What mission were they on?

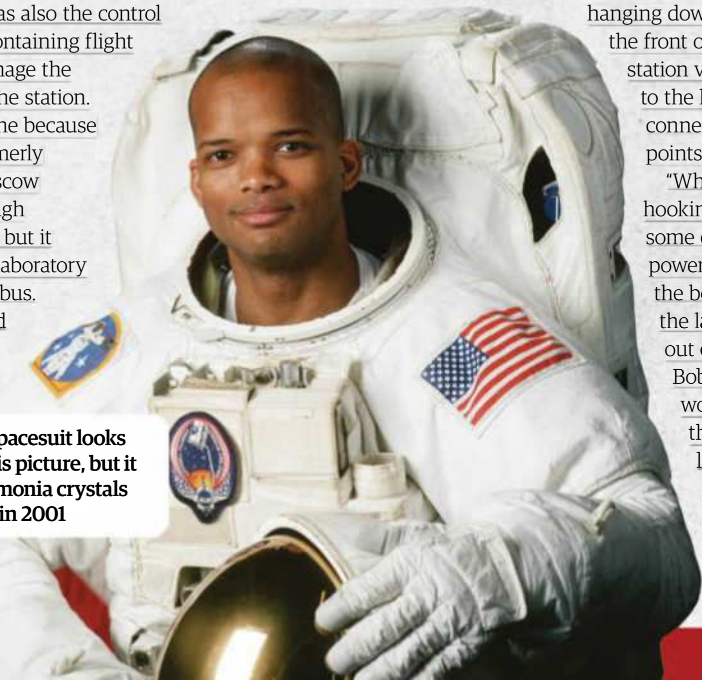
The STS-98 mission which launched on 7 February 2001 and lasted for 12 days, 21 hours and 20 minutes.

"The big objective of the mission that day was to install the US Laboratory, Destiny. Not only was it a science lab, it was also the control centre for the ISS containing flight computers that manage the operations aboard the station. It was a big milestone because the control was formerly handled by the Moscow control centre through the Zvezda module, but it involved moving a laboratory the size of a school bus.

"It had to be lifted by a robot arm from the cargo bay of the space shuttle, Atlantis, before being plugged into the front of the space station and bolted permanently into place. Robert Curbeam and I did our first of three spacewalks on 10 February 2001. We were to disconnect cables and remove protective covers from the outside hatch of Destiny.

"If we didn't get the lines installed the lab would overheat or freeze, and we wouldn't be able to control the systems on board the space station as we anticipated for the rest of the mission. We had choreographed our task for hundreds of hours underwater and we were spinning through a very well-rehearsed mission. We had to access a tray of cables and cooling lines hanging down from the front of the space station very near to the laboratory's connection points.

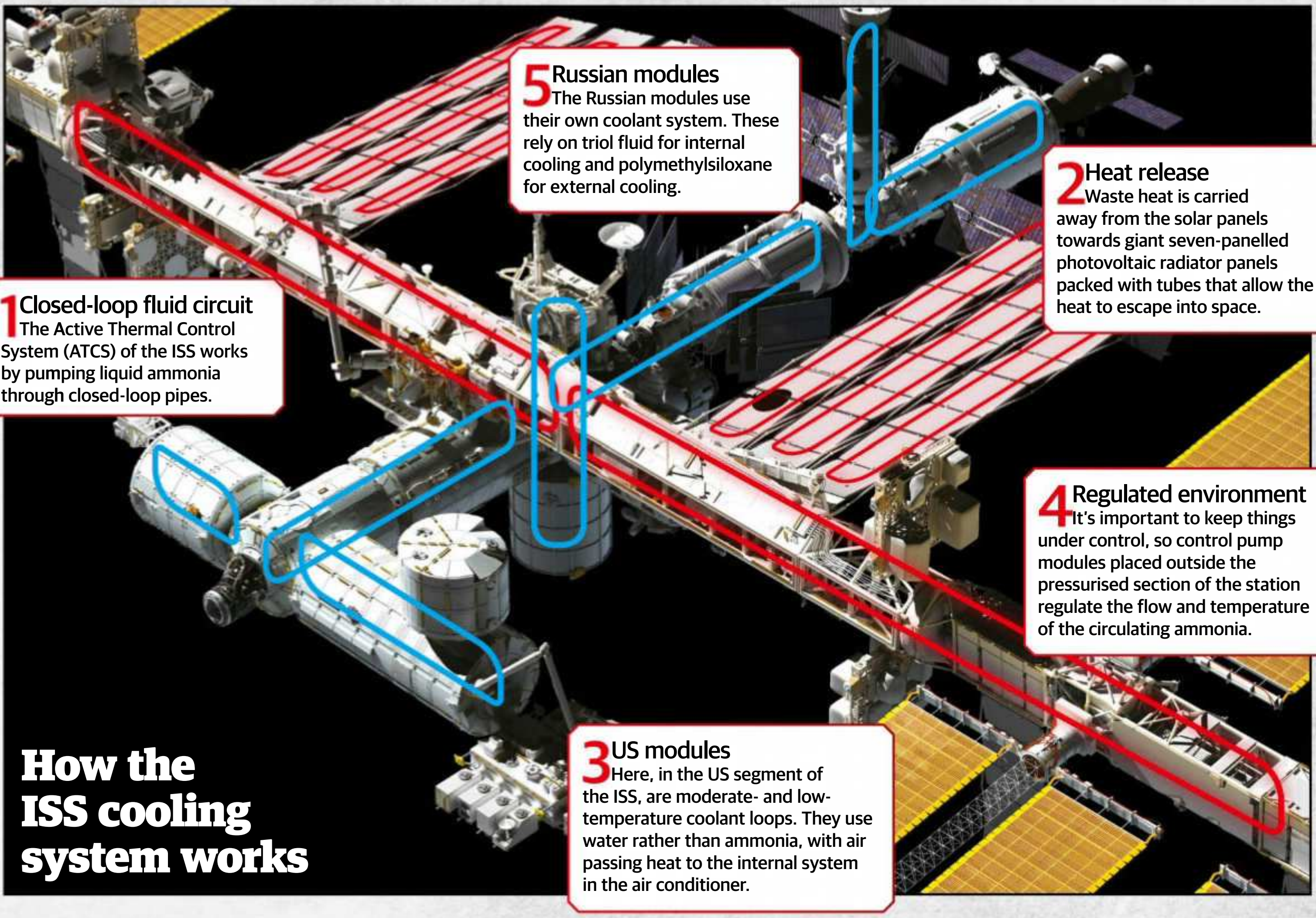
"While I was hooking up some electrical power lines on the bottom of the lab, I was out of sight of Bob, who was working with the cooling lines on the top. He was



Robert Curbeam's spacesuit looks nice and clean in this picture, but it was caked with ammonia crystals during the incident in 2001

When ammonia crystals meet spacesuit fabric

Curbeam wasn't in any danger while he continued to wear his spacesuit – it offered more than enough protection from the frozen ammonia crystal flakes.
The main immediate danger was in losing ammonia from the ISS' cooling system.
It is limited in supply and there was a chance the lab's operations would have been greatly reduced as a result.
There was also a worry about what to do after the leak had been choked off. Ammonia could not be allowed to contaminate the interior of the ISS: it is a highly toxic chemical.
For that reason, Jones had to remove all of the ammonia from Curbeam and himself.
Since the ammonia crystals would evaporate in the Sun's heat, Curbeam was ordered to stay outside for an extra orbit.
Once he returned inside, the remaining crew wore oxygen masks while the shuttle's life support systems removed any remaining ammonia in the air.



How the ISS cooling system works

> "In realising the seriousness of the problem and by going into play with his knowledge of the system, Bob saved so much" **Tom Jones**

intending to detach the first one before bending it over to plug it into the laboratory. But when he freed it from the station the valve did not close fully, and it began venting a steady stream of ammonia vapour. This was a concern. When hydrous ammonia hits the vacuum of space the gas instantly freezes into a solid, so you get these big ammonia snowflakes coming out of the end of the line along with the visible vapour.

"Bob was straight on the radio reporting a leak, but because I wasn't there to see it I just thought it was some little puncture – a bicycle-tyre kind of leak. But as the conversation with our pilot Mark Polansky back in the shuttle continued, I could tell he was more concerned from the tone of his voice. So I said, "Bob, you need my help there?" And he replied, "Yeah, I think so." I looked up past the edge of the laboratory hull and I could see this cloud of vapour against the black sky expanding from where he was. There were these fat snowflakes tumbling along with the vapour jet and it looked like a comet tail of glistening sunlit snowflakes wafting across the sky.

"It was more like an expanding cloud or a vapour stream that was carrying these snowflakes in a sort of lazy fashion out of the station. But we knew that was very bad because there's a limited coolant supply aboard the space station. The worry was we'd end up with a deficient or inoperative cooling system and that the flight computers and their associated life support gear could not be turned on. We'd end up with a crippled laboratory, so it was vital to stop that leaking ammonia.

"I started to climb up towards Bob. He was standing in a foot restraint that gave him hands-free access, and he knew that upstream of this leaky end of the hose was another shut-off valve that could interrupt the ammonia flow. Trouble was it was at the far end of his reach from standing on this foot platform, so he had to stretch himself out to grab on to the structure with one hand and then single handedly operate the mechanism. It's normally a two-handed operation and he had to really bend this thing over using his strength. By the time I got up there he was able to interrupt the flow, but the valve areas looked like a drift of piled-up snowflakes and Bob had a lot of this snow on his spacesuit front.

"Our suits protected us but there was no chance of going back inside straight away. There was a potential that we'd be struck by a micro-meteoroid, for example, that would puncture our suits, and because we'd be unable to get back into the airlock and open up the interior of the hatch, the situation would be dicey. Even so, for the next hour or so we literally brushed away this snow, cleaned the valve and connector area and moved on to connecting those hoses. We lost about five per cent of the ammonia quantity, but in realising the seriousness of the problem and by going into play with his knowledge of the system, Bob saved so much. We had to decontaminate throughout the rest of the spacewalk, though. Bob had to park in the sunshine for 30 to 45 minutes and I had to go get a brush from the tool box and sweep a few random snowflakes off.

"We then had our decontamination procedure to follow inside the air lock to make sure we were not bringing back any random ammonia crystals. Since that stuff is highly attracted to water and a hydrous ammonia is so chemically active, the danger is that it adheres to the moisture in your lung lining which destroys it. For that reason, it was critical we didn't bring that stuff back into the cabin atmosphere, so we had to flush out the atmosphere in the air lock and use wet towels tossed to us to wipe down the suits and airlock walls. Those moist towels adhered to and attracted the hydrous ammonia crystals. Thankfully it all worked out."

Tom Jones recounts some of the ups and downs of life in space in his book, *Sky Walking*

"My glove had sealed up against the stainless steel palm bar"

Jerome Apt's spacesuit glove was punctured in the vacuum by a metal rod, causing him an injury

What happened?

As astronaut Jerome Apt performed an Extravehicular Activity, it was discovered that the palm bar in his right glove had punctured his suit. Although he was unaware of what had happened at the time, it left him partially exposed to vacuum.

What mission were they on?

STS-37 Atlantis in 1991. It was his first spaceflight and he had been performing his second EVA over the course of five hours and 47 minutes.

"You know what the highest danger in space flight is; the thing that can result in an excruciating painful death? Driving to work. If you look at the risk of a launch or a landing accident, then there have been two crashes of the Shuttle in 135 flights. That's a chance of one in 67.5 and, since I flew four times, you can - with high school maths - calculate that my chances of being in a crash of the shuttle were one in 17. Compared to that, the risks of a spacewalk were no big deal.

"I had returned from the second successful EVA of STS-37 and my crewmates Ken Cameron and Linda Godwin were helping Jerry Ross and I with the suits in the airlock. Linda helped me take off my gloves and comfort gloves and she noticed I was bleeding. "Fine," I said. "No big deal." The suit is very painful in a number of areas as the fabric folds over and presses into your skin, and I had some painful areas on that EVA - my upper arm and leg in a couple of places. But that's just kind of normal for the suit, so I didn't think much of this.

"We slapped a Band-Aid [plaster] on the cut and I got on with my work. A couple of nights after we landed home I got a call from the suit manager who said that the post-flight team had noticed that there was a tiny hole in the glove. They had noticed absolutely no degradation of pressure and, of course, suits are instrumented heavily so that you can spot additional flows of oxygen. But while they didn't even deviate one count from what was normal, there was a hole nevertheless.

"It was found that the material of the glove had sealed up against the stainless steel palm bar, a C-shaped stainless steel piece that prevents the glove material from billowing out as it would under nearly 5psi of pressure. That had worked its way out of its restraints and, through the course of the two EVAs, worked its way into the glove's material, which is a very sticky rubber. Now the palm bar itself is only so wide, and it was pretty much through as much as it was going to go through, so the design of the suit proved to be really good.

"But the people who worked on the suits were able to quickly change the design of the restraint of this palm bar so that it wasn't likely to happen again to anyone in the future. It was the kind of thing that you learn through a well-monitored programme, and the suit folks at Johnson Space Center did an excellent job, with the redesign completed along with the contractors quite quickly. The suits still fold over and get squeezed on to your skin and causing you to be black and blue for a while, but it's just another day at the office, I guess."

A fully suited Jay Apt poses for his official portrait image for NASA

Jay Apt embarks on the first EVA of STS-37. His incident occurred when he stepped out for his second spacewalk

"Suddenly my left eye slammed shut in great pain"

Chris Hadfield was temporarily blinded while holding on to the exterior of the International Space Station

What happened?

Canadian Space Agency astronaut Chris Hadfield suddenly felt pain in one of his eyes while he was on his first ever spacewalk. Within a short time his other eye was also affected, plunging him into even greater darkness as he worked on the ISS.

What mission were they on?

Hadfield was Mission Specialist 1 on STS-100, his second-only spaceflight, and he was working to deploy a UHF antenna on the Destiny lab.

Luckily this bubble was not about to cause Hadfield any trouble

"In April 2001, I became the first Canadian to walk in space. I performed two spacewalks. The first one felt comfortable and familiar; I knew what I was doing. I felt confident. I knew that no matter what went wrong I could deal with it, but I was blinded during that spacewalk. Suddenly my left eye slammed shut in great pain and I couldn't figure out why it wasn't working. But I kept going and because without gravity tears don't fall, the ball of whatever was mixed with my tears on my eye got bigger and bigger. Eventually it became so big, the surface tension took it across the bridge of my nose like a tiny little waterfall and went 'goosh' into my other eye. Now I was completely blind.

"It turned out we had contamination in the suit and it blinded both of my eyes for about half an hour. It was pretty unexpected to be outside the spaceship, blind and holding on, hoping my vision would clear. But rather than panic - which would be a natural reaction - my training took over. By that point we knew everything there is know about the spacesuit and had trained underwater thousands of times. We don't just practice things going right, we practice things going wrong all the time, and not just underwater, but in virtual reality labs with the helmet and the gloves so you feel like it's realistic. The panicky reaction didn't happen.

"I might actually have been struck blind permanently. In fact, some of the chemicals in the suit are toxic enough that they could permanently damage the mucous membrane, so that could have been very bad. But it wasn't. It was something much more minor. Just because something makes you feel vulnerable and uncomfortable doesn't mean its necessarily dangerous or risky. The key is to look at the difference between perceived danger and actual danger: where is the real risk? What is the real thing that you should be afraid of? Not just a generic fear of bad things happening.

"So I wasn't really afraid because it was just that my eyes were not working. I thought, 'OK, I can't see, but I can hear, I can talk', and Scott Parazynski, my partner on the spacewalk, was there with me, and he could float me like a blimp and stuff me into the airlock if he had to. And actually if I kept on crying for a while then whatever that gunk was in my eye would start to dilute and I could start to see again.

"So I was more worried that we weren't going to get the spacewalk done because time is really tight. It's like when you get a bug in your eye or if you get shampoo in your eyes so that you can't see in the shower. You're not really afraid, just sort of irritated. Fortunately it eventually cleared and I could see again, and so we got everything done. When I came back inside, Jeffrey S. Ashby got some cotton batting and took the crusty stuff around my eyes.

"It turned out it was just the anti-fog, sort of a mixture of oil and soap that is used to polish the spacesuit visor, that got into my eye. Now we use Johnson's No More Tears, which we probably should have been using right from the very beginning. I went on to perform a second spacewalk and I spent a total of 14 hours 50 minutes outside, travelling ten-times around the world during that time."

Did you know?

As a pilot aboard Gemini 9A in 1966, Eugene Cernan logged over two hours on a spacewalk. Because so few people had worked in space, no one knew just how challenging simple tasks could be in micro-gravity. Cernan was totally exhausted and covered in sweat from the work outside the craft, but he couldn't take off the suit. He was forced to abandon his mission and blindly scrabble back to the craft. He arrived back safe, but dehydrated.

Going Blind

How and why Chris Hadfield's vision suddenly disappeared

Anti-fogging chemicals
NASA began to apply anti-fogging chemicals after astronaut Eugene Cernan's suit became waterlogged with sweat and fogged up his visor in 1966.

Contacting his eye
The anti-fogging agent came into contact with Chris Hadfield's left eye mid-spacewalk in 2001. It began to sting and caused his eye to fill with tears.

Moving to the other eye
The tears formed a blob of fluid which then began to move across the bridge of his nose before affecting his right eye too. This rendered Hadfield fully blind.

Flushing the anti-fog away
Hadfield's eyes continued to water heavily, but this worked in his favour. It began to dilute the anti-fog agent to the point that it flushed away, allowing him to see once more and finish the EVA.

"There was immediate pain, but there was also blurred vision"

Norman E Thagard feared for his sight when a freak accident affected one of his eyes on board the Russian space station Mir

What happened?

Research astronaut Norman E Thagard was performing deep knee-bend exercises when an elastic foot strap slipped away and ended up slapping him in his right eye, causing him great pain whenever he saw light.

What mission were they on?

Thagard was on the Soyuz TM-21 mission which launched on 14 March 1995.

"I was a crew member for the Russian Mir EO-18 mission and I had gone to the space station aboard Soyuz with commander Vladimir Dezhurov and Gennady Strekalov. It was my fifth spaceflight in a space career that began in January 1978 when I was selected as an astronaut candidate. I had first flown with the crew of STS-7 which launched from the Kennedy Space Center in Florida on 18 June 1983. My mission in 1995 was to be my last.

"I am writing a book about my Mir experiences which will be based on the diary I kept while on board, but without referring to that, I recall there being 'expanderee' on board the space station. This is a Russian term for stretchable cables that required strength to expand. They are sometimes seen in gyms for repetitive stretching exercises to build or maintain muscle strength and one such piece of gym equipment was long enough to stretch from one foot up to and around the back of the neck, over the shoulders and down to the other foot, with each foot inserted into a stirrup.

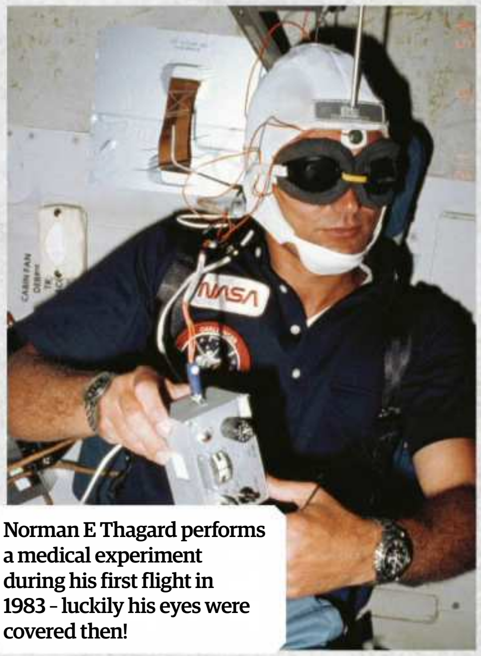
"I used this cable to perform repetitive deep knee bends which is essentially a full squat strength-training exercise that can burn fat and increase flexibility. While engaged in this activity during one of my scheduled exercise periods, the stirrup slipped off one of my feet and, because I was almost 'standing' (remember I was working in a zero-g environment), the cable was on the stretch. This meant that it was under a considerable amount of tension.

"Due to this tension, when the stirrup slipped off my foot, it flew off at high speed. Within a split second it had struck me in the right eye. As you can imagine there was immediate pain, but there was also blurred vision in that eye. Later on, I noticed photophobia - a symptom of abnormal intolerance to visual perception of light that causes discomfort or pain due to light exposure. This happened even with low-intensity light.

"Since I am a physician, I tried to use a mirror to perform an eye examination on myself but I could not identify any sign of injury. The pain was intense so I used anaesthetic eye drops in the affected eye and then I patched it to avoid any further inadvertent injury to the desensitised eye. I told Strekalov what had happened and he joked, "Oh, yes. Those things are dangerous. That's why I don't use them." "Thanks, Gennady, for the heads-up on that one," I responded.

"I was able to get a consultation with a Russian ophthalmologist at Mission Control, Moscow and I followed his recommended action, but the eye did not seem to improve. After a day or two, the ophthalmologist decided the injury was likely a corneal abrasion and recommended new treatment. I applied steroid drops, which the space station had readily available, and the injury then seemed to quickly resolve and get back to normal.

"After the mission, however, one of the NASA eye doctors suggested that the injury may have accelerated the progress of the cataract in the lens of my right eye. I am not an ophthalmologist and I did not research the possibility that the injury could have affected the cataract, but it is true that the right lens required replacement more than three years before the left eye's lens."



Norman E Thagard performs a medical experiment during his first flight in 1983 – luckily his eyes were covered then!

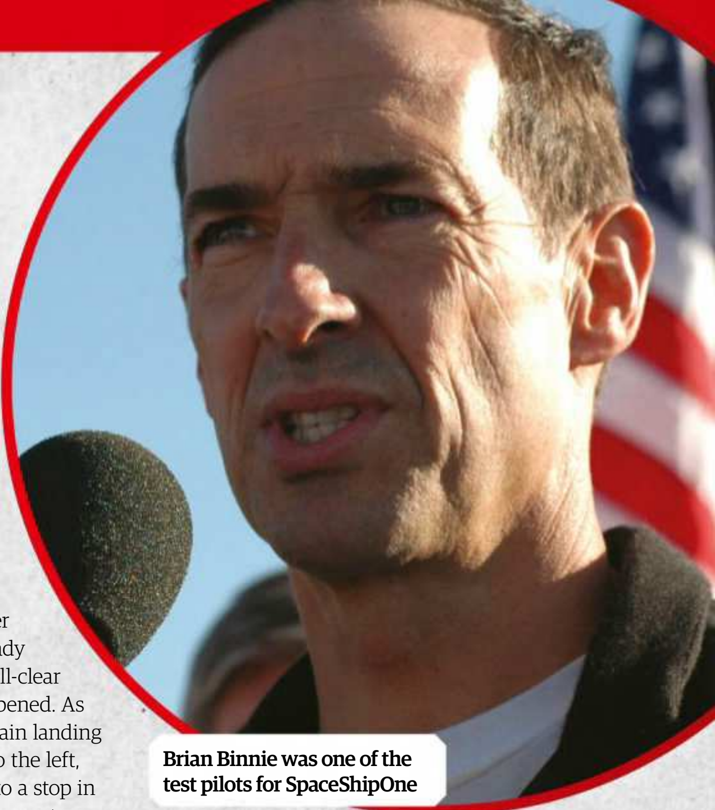
Did you know?

Many astronauts experience poorer vision after spaceflight. Vision can remain affected for years afterwards.

> "The injury may have accelerated the cataract in my right eye" **Norman Thagard**

"I crashed SpaceShipOne"

Brian Binnie successfully piloted the first privately funded manned craft to achieve supersonic flight – and then crashed it



Brian Binnie was one of the test pilots for SpaceShipOne

What happened?

American test pilot Brian Binnie took SpaceShipOne on its first rocket-powered flight, but a difficult landing caused damage to the landing gear and sent it careering off the runway.

What mission were they on?

Flight 11P of SpaceShipOne, the first private manned space vehicle.

"Flying the first powered test flight of the privately funded, experimental, air-launched, rocket-powered aircraft SpaceShipOne – flight 11P – on 17 December 2003 was a chance of a lifetime. The day marked 100 years since the Wright Brothers made their first powered flight and the aircraft was capable of reaching 900 metres (0.5 miles) per second using a hybrid rocket motor.

"But at the time, expectations were low. Just getting the motor lit would have been considered a success, so there was nothing to lose from the point of view of a pilot. However, that meant it was all the more exciting to see the motor light, and the aircraft achieved a 15-second burn before turning over and coasting upside down at 68,000 feet. It became the first civilian craft to achieve supersonic flight, reaching a top speed of Mach 1.2 (1,287 kilometres or 800 miles per hour) after just nine seconds, and that was some achievement. On the glide back down there was little to do other than enjoy the ride.

"And so it began. After descending to 35,000 feet for a minute with the feather deployed, it was time to start getting ready to land. The gear was lowered and the all-clear was given, but then a terrible thing happened. As SpaceShipOne touched down the left main landing gear collapsed. It crashed and skidded to the left, running off the runway before coming to a stop in soft sand. It was a sore sight indeed: the gear torn and the spacecraft full of desert dirt, lying damaged with pilot and craft's pride hurt.

"It wasn't the end of SpaceShipOne, though. Come 21 June 2004, Mike Melvill had piloted the craft on its first flight past the edge of space and, on 29 September that year, he flew the three-person rocket ship on the first of two flights to capture the $10 million Ansari X prize for the first privately built vehicle to haul a pilot and two passengers to the edge of space. It made a series of rolls near the top of its flight which frightened some watching on the ground, but it was a hugely successful venture."

Did you know?

On 31 October 2014, the VSS Enterprise – the first of five planned SpaceShipTwo crafts – was performing a test flight over the Mojave Desert, California when something went drastically wrong. Investigators determined that the feather system was released too early at speeds of Mach 0.92 (1,127 kilometres or 700 miles per hour), causing the craft to break apart. While sadly co-pilot Michael Alsbury perished in the incident, the pilot ejected and survived.

> "The gear was lowered and the all-clear was given, but then a terrible thing happened" **Brian Binnie**

SpaceShipOne repaired and ready for its 21 June 2004 flight

"The spacecraft went roll, roll, roll, roll"

The Soyuz TMA series of spacecraft used by Russia's space agency

Don Pettit was on the Soyuz TMA-1 when a technical malfunction caused a ballistic re-enty

What happened?

Don Pettit, Kenneth Bowersox and Nikolai Budarin were on board the Soyuz TMA-1 spacecraft for their journey back to Earth only to suffer about eight-times the force of gravity during re-entry and a landing some 275 miles short of the planned area.

What mission were they on?

Expedition 6, which had been extended by two months following the Columbia disaster in which the space shuttle broke apart over Texas during its re-entry on 1 February 2003.

The Space Station can be a home away from home, a place where you can be with an outstanding group of talented folks and work on the frontier. Leaving can be hard. From spending six months on board the ISS for Expedition 6 in 2002 and 2003, to being a mission specialist on the STS-126 mission in 2008 and part of the Expedition 30/31 crew in 2011 and 2012, there are great times both personally and for science. Coming back in 2003, however, was particularly tough.

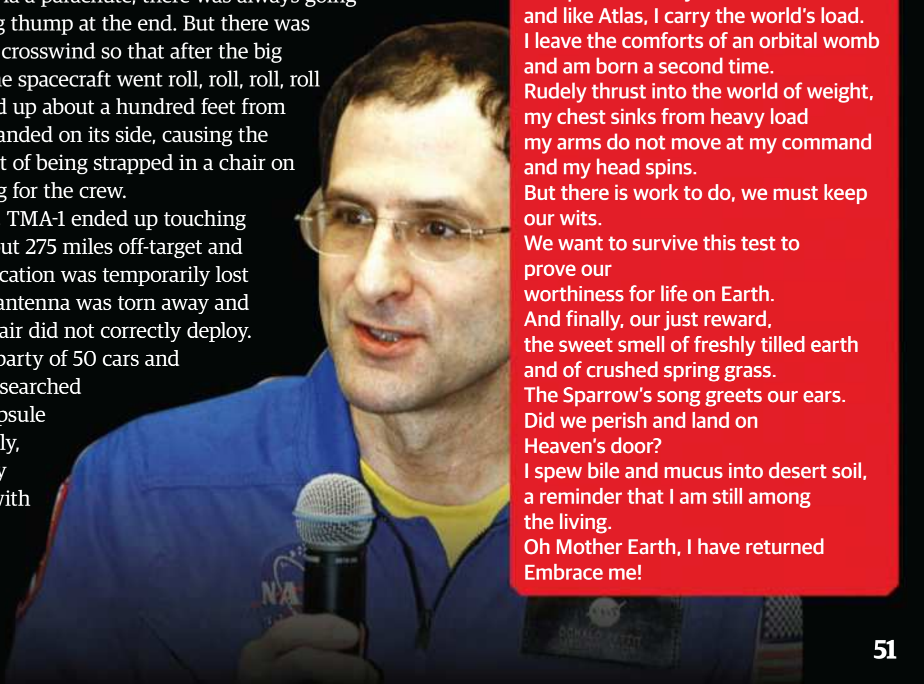
The crew returned on a Soyuz spacecraft for a landing on the desert plains of Kazakhstan. Unlike the Space Shuttle, there was precious little room for personal effects on board Soyuz, but it allowed three crew members to climb aboard.

The time came five days after the Expedition 7 crew arrived at the station on a TMA-2 spacecraft on 28 April. Having been relieved, the Expedition 6 crew could then use the TMA-1 spacecraft that had flown Frank De Winne, Sergei Zalyotin and Yury Lonchakov to the station on 1 November the previous year. But this is when things began to get interesting.

The Soyuz was a robust vehicle. It had a lot of safety built into its very engineering design and it had the equivalent of two spare tyres. But it is notorious for rough landings, and that's independent of whether you do a ballistic entry or not. By ballistic, we're talking of a re-entry in which the capsule behaves like a spherical object. It's a contingency mode that lends greater stability, but it leads to a steeper trajectory, less landing precision and increased gravity loads.

In this case the crew experienced a ballistic entry and used one of the spare tyres coming in. Landing via a parachute, there was always going to be a big thump at the end. But there was sufficient crosswind so that after the big thump, the spacecraft went roll, roll, roll, roll and ended up about a hundred feet from where it landed on its side, causing the equivalent of being strapped in a chair on the ceiling for the crew.

Indeed, TMA-1 ended up touching down about 275 miles off-target and communication was temporarily lost when an antenna was torn away and another pair did not correctly deploy. A search party of 50 cars and 15 planes searched for the capsule and, luckily, eventually found it with everyone safe and well.



A verse-atile space traveller

Following his Soyuz TMA-1 landing in 2003, Don Pettit penned a poem about the intensely nail-biting experience

Oh Mother Earth, embrace me
with all of your weight.
I am pressed into your bosom
and like Atlas, I carry the world's load.
I leave the comforts of an orbital womb
and am born a second time.
Rudely thrust into the world of weight,
my chest sinks from heavy load
my arms do not move at my command
and my head spins.
But there is work to do, we must keep
our wits.
We want to survive this test to
prove our
worthiness for life on Earth.
And finally, our just reward,
the sweet smell of freshly tilled earth
and of crushed spring grass.
The Sparrow's song greets our ears.
Did we perish and land on
Heaven's door?
I spew bile and mucus into desert soil,
a reminder that I am still among
the living.
Oh Mother Earth, I have returned
Embrace me!

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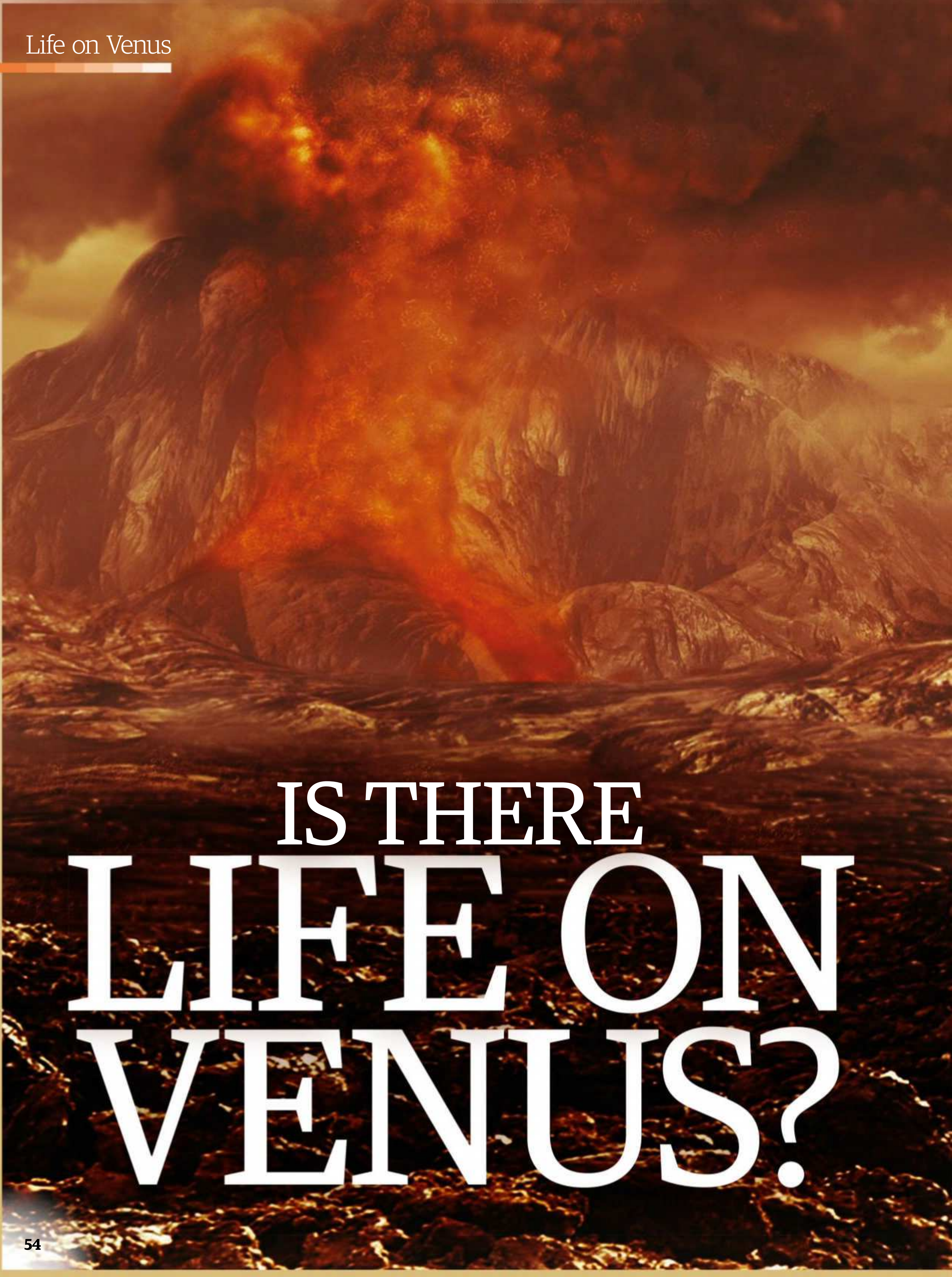


IS THERE LIFE ON VENUS?

The question of whether Venus' clouds could host life has been around for 50 years, but new research suggests that it's the best place to look

Reported by Abigail Beall

The second rock from the Sun is a strange and harsh place. Temperatures are hot enough to melt lead, it has a crushing pressure of over 90-times that of the Earth and a carbon dioxide-rich atmosphere that has caused a runaway greenhouse effect. Despite this, evidence is mounting to suggest life could have once existed, or may still exist, on Venus.

When it comes to extraterrestrial life in our Solar System, Venus is not the most obvious place to look. The recently discovered plumes of water on Europa or clouds evaporating from Enceladus mean these two moons take the top spot for potential life, while Mars, with its known history of being covered in oceans, is a consistent contender for third place. Venus, however, does not usually get a look in.

"Venus is a harsh place - the clouds are sulphuric acid, as well as the harsh surface conditions," says Andrew Coates, Professor of Physics at University College London. "Even where the clouds are water it's unlikely that the conditions are right for life. What is needed is liquid water, the right chemistry, a source of energy and enough time for life to develop. It's very unlikely those conditions are met in the Venus atmosphere."

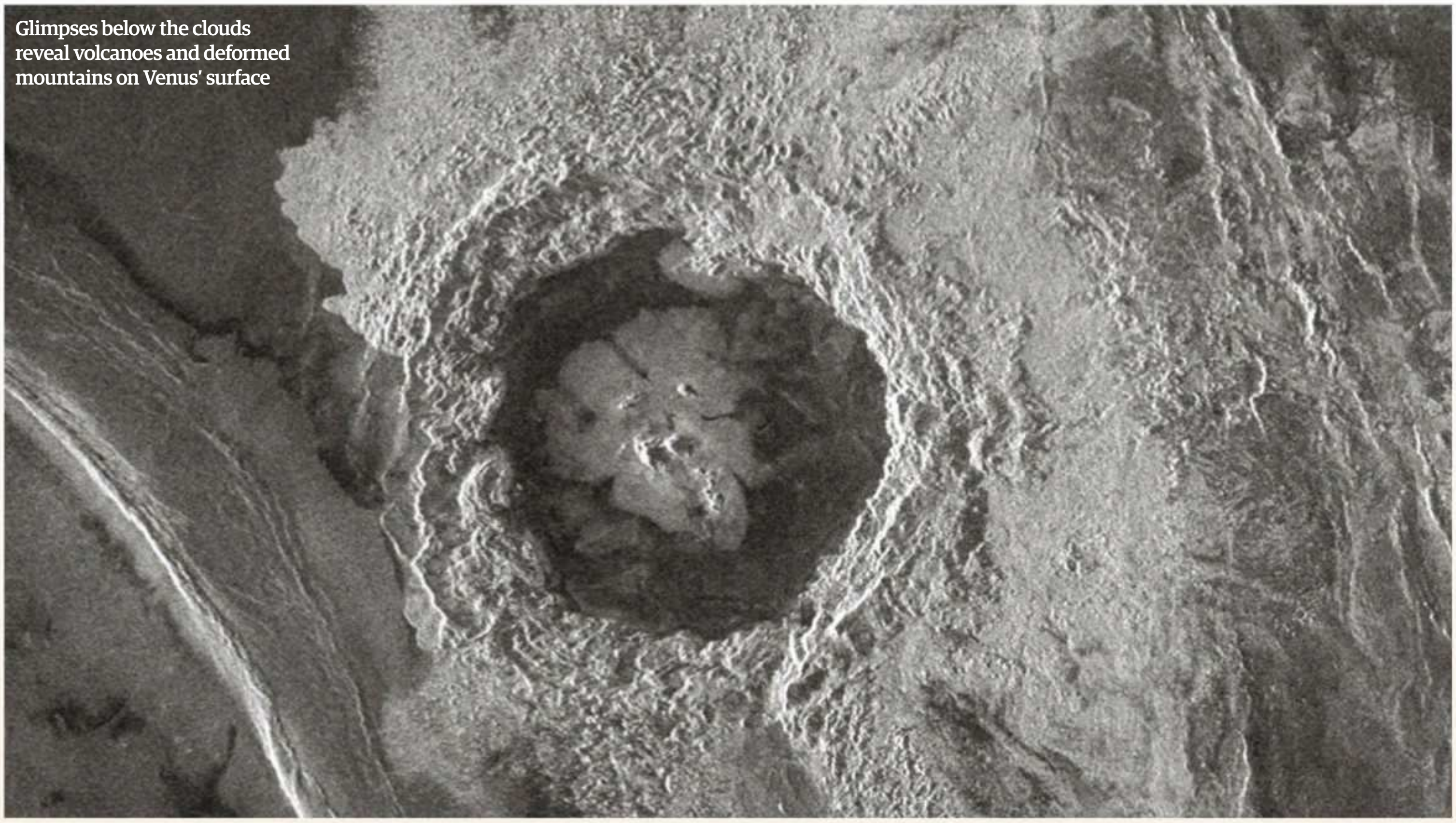
Decades ago, the idea of Venus hosting life was not so absurd, however. In 1870, British astronomer Richard Proctor suggested that life could possibly exist at the planet's poles, and it was thought the conditions might be similar to those on Earth.

> "Venus is a harsh place - the clouds are sulphuric acid, as well as the harsh surface conditions"
> **Prof Andrew Coates**

Only when we started to study Venus in more detail in the 1960s was this idea thrown out. Spacecraft studies of the planet revealed just how unfriendly it really is on Venus, sending the idea that liquid water could exist on its surface, a marker for potential life, down the drain.

A few years later, the idea of Venus as a host of extraterrestrial life came back on the table. Astronomer Carl Sagan and his colleague Harold Morowitz published a paper in 1967 called 'Life in the Clouds of Venus?' in *Nature*, suggesting that while Venus' surface would experience far too much pressure and high temperatures for life, its clouds could be a different story. "While the surface conditions of Venus make the hypothesis of life there implausible," the paper begins, "the clouds of Venus are a different story altogether." The pair argued that small quantities of minerals could be stirred up into the atmosphere from the planet's surface, and as a result the atmosphere might be home to a few bits of biology.

Fast forward 50 years, and the idea of life in Venus' clouds is still something researchers are looking into today.



Glimpses below the clouds reveal volcanoes and deformed mountains on Venus' surface

"Surface temperatures on present-day Venus are too high for life," says David Holmes, from the Science and Life Foundation in Santiago, Chile. "It is thought that subsurface temperatures are also too high – so no refuges underground, unlike Mars. The only possible refuge for life would be in the clouds."

Holmes and his colleagues have been working on this theory. The team will attend the Astrobiology Australasia meeting later this month in New Zealand to present a new paper arguing we should reassess the possibility of life on Venus. Their argument is that recent models suggest that Venus may once have been home to a liquid water ocean that may have covered 60 per cent of its surface.

"Life needs liquid water and there isn't very much on Venus today," says Holmes. "However, a recent model of early Venus suggests that a water ocean once existed on Venus and may have lasted two billion years." In a paper published in 2016, Michael Way, a researcher at NASA's Goddard Institute for Space Studies, and his team modelled Venus' atmosphere using data from the Magellan mission, which arrived at Venus in 1990. They concluded that Venus may once have had an ocean, much like we believe early Mars had. This may have lasted for up to 2 billion years, and Venus' climate could have stayed habitable until at least 715 million years ago.

"It took life on Earth less than a billion years to evolve and so, if early Venus had similar conditions as early Earth, then it is possible that life also evolved on Venus," says Holmes. Another theory is life from Earth could have been transferred to Venus during a collision between the two planets in the early Solar System.

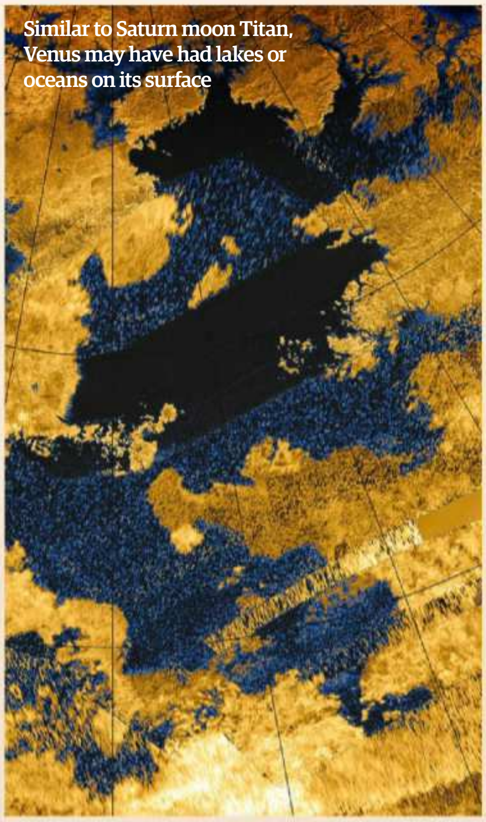
"An early water ocean has also been proposed for Mars, and this idea has received a lot of support from observational evidence," says Holmes. "Such evidence is still needed for Venus' proposed ocean."

> "A recent model of early Venus suggests that a water ocean once existed and may have lasted 2 billion years" **David Holmes**

What's more, and what Holmes and his colleagues are arguing, is if Venus once had an ocean, life that brewed in that ocean could still be lingering around the planet, now in its atmosphere. The temperatures in some layers of the clouds, at altitudes between 40 and 60 kilometres (25–37 miles), are favourable for life, they say, and sulphur compounds in the atmosphere could act as an electron donor/acceptor to help sustain life.

On top of this, the acidity of Venus' clouds that is often cited as inhospitable for life could help it to thrive, based on observations on Earth. In Chile's Atacama Desert, life thrives in conditions with a low pH and very little water. Life in these extreme conditions mainly exists in the form of bacteria and archaea. They derive energy from the oxidation of inorganic substrates such as sulphur, iron and hydrogen, fixing carbon and nitrogen from the atmosphere. Examples, known as acidophiles, can be found on every branch of the tree of life, Holmes and his colleagues argue. One example close to home are among the types of bacteria common in the human gut.

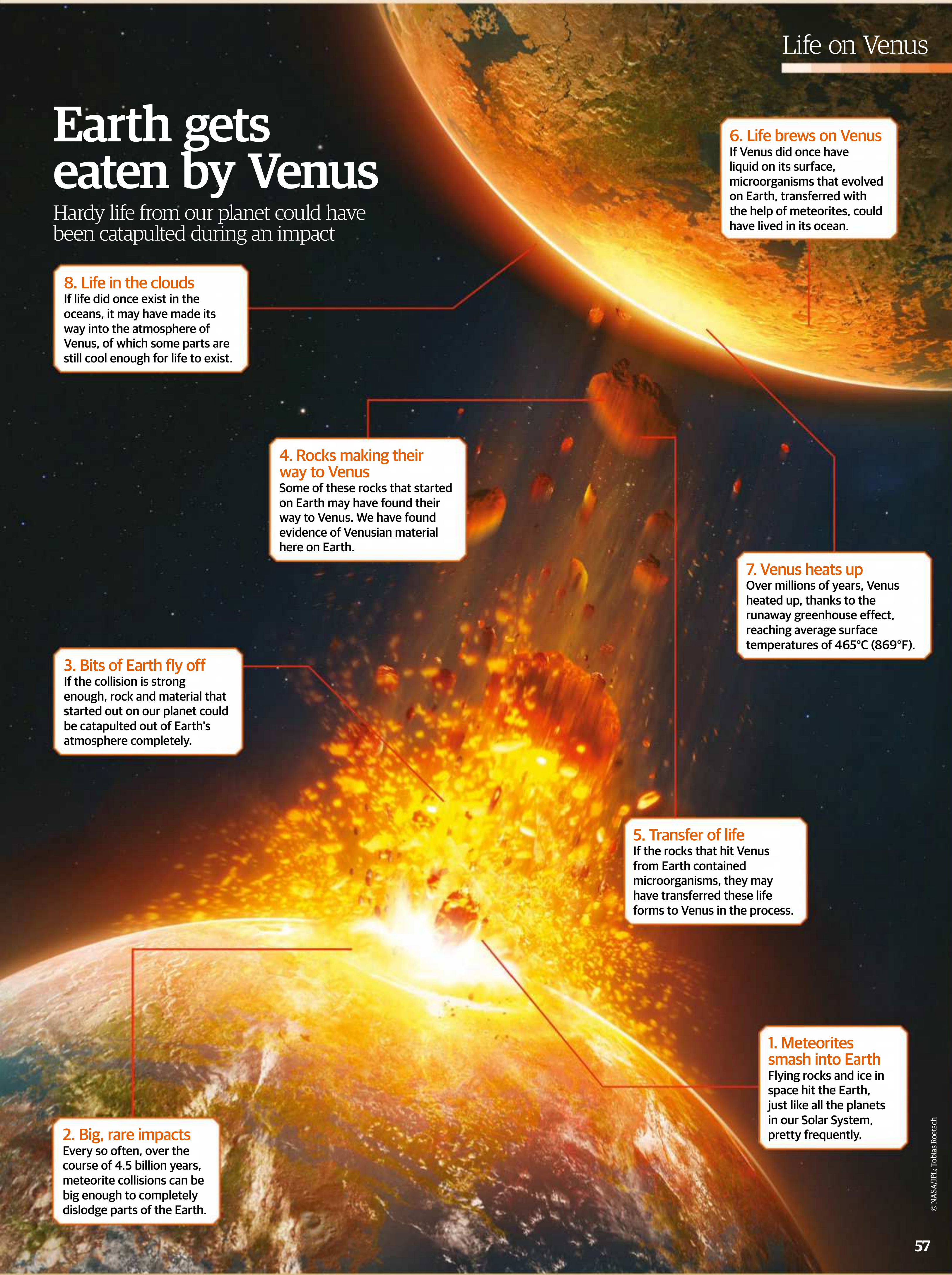
While these theories are exciting, they mean little until direct evidence is discovered. This is why Sanjay Limaye, planetary scientist at the University of Wisconsin-Madison, thinks we need to turn to



Similar to Saturn moon Titan, Venus may have had lakes or oceans on its surface

Earth gets eaten by Venus

Hardy life from our planet could have been catapulted during an impact



1. Meteorites smash into Earth
Flying rocks and ice in space hit the Earth, just like all the planets in our Solar System, pretty frequently.

2. Big, rare impacts
Every so often, over the course of 4.5 billion years, meteorite collisions can be big enough to completely dislodge parts of the Earth.

3. Bits of Earth fly off
If the collision is strong enough, rock and material that started out on our planet could be catapulted out of Earth's atmosphere completely.

4. Rocks making their way to Venus
Some of these rocks that started on Earth may have found their way to Venus. We have found evidence of Venusian material here on Earth.

5. Transfer of life
If the rocks that hit Venus from Earth contained microorganisms, they may have transferred these life forms to Venus in the process.

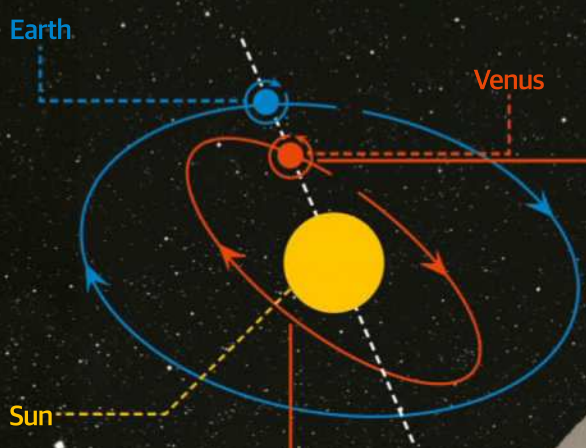
6. Life brews on Venus
If Venus did once have liquid on its surface, microorganisms that evolved on Earth, transferred with the help of meteorites, could have lived in its ocean.

7. Venus heats up
Over millions of years, Venus heated up, thanks to the runaway greenhouse effect, reaching average surface temperatures of 465°C (869°F).

8. Life in the clouds
If life did once exist in the oceans, it may have made its way into the atmosphere of Venus, of which some parts are still cool enough for life to exist.

What's Venus like?

Although sometimes called 'Earth's Twin', the two are nothing alike



Venus' strange rotation

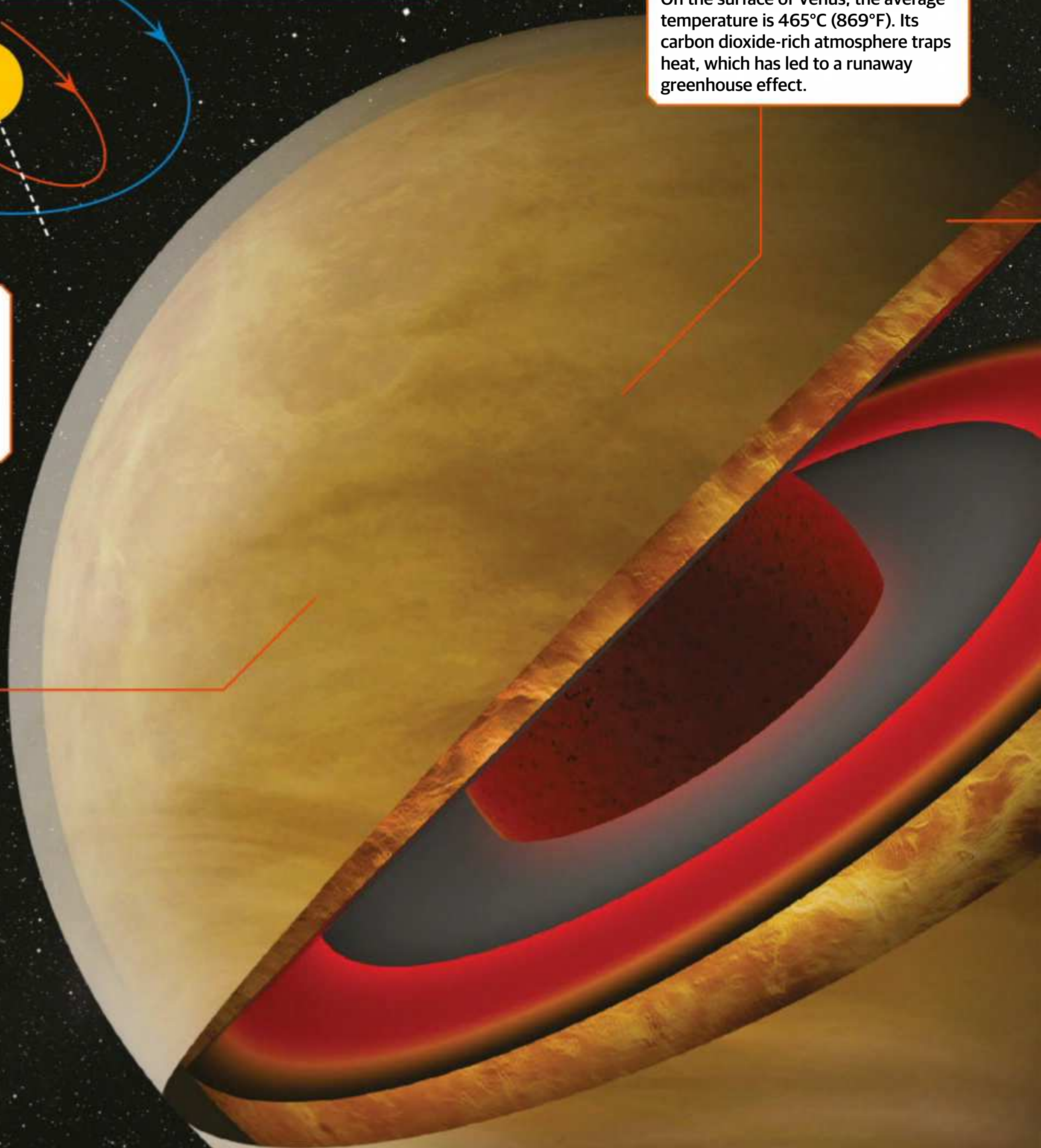
Venus is one of just two planets (the other being Uranus) to rotate in the opposite direction to the rest of the planets as it orbits the Sun (retrograde rotation).

Venus' surface

On the surface of Venus, the average temperature is 465°C (869°F). Its carbon dioxide-rich atmosphere traps heat, which has led to a runaway greenhouse effect.

Venus' orbit

Due to its slow rotation, a sidereal day on Venus (243 Earth days) is longer than a year on the planet (225 Earth days). It also has the most circular orbit around the Sun of any other planet in our Solar System.



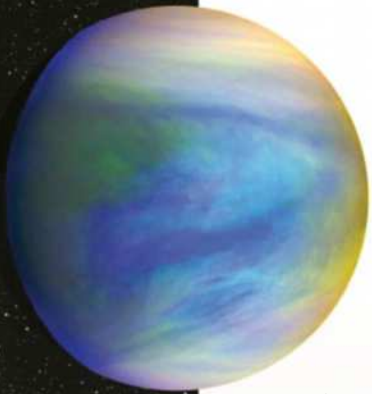
Volcanoes on Venus

The planet is covered with volcanoes; it has shield volcanoes, lava flows and some unusual peaks known as pancake domes.

Venus has more volcanoes than any other planet in the Solar System.

Venus has a very weak magnetic field.

Venus' surface is the hottest of any planet's in the Solar System.



A composite image of the planet Venus as seen by the Japanese probe Akatsuki. The clouds could have environmental conditions conducive to microbial life

images of Venus' atmosphere.

Limaye and his team recently published a paper that re-ignited interest in the atmosphere of Venus as a potential place for life to exist. First the team looked at the information we have from past missions and the ideas, like those from Holmes and his colleagues, about the past presence of liquid water on the surface of Venus. Then they decided to pursue the same line of reasoning that has been applied to Mars and other ocean worlds, like Europa and Enceladus. They decided to 'follow the water'.

Using this reasoning, Limaye says, "the possibility of life on Venus in its past, when it had liquid water on the surface and had habitable climate, cannot be excluded." Taking this a step further, he says, it is viable that life could be there in the clouds, where the conditions are conducive to the presence of life similar to the organisms found in Earth's clouds.

In order to test the theory, Limaye looked into the mystery of Venus' atmosphere that requires a different perspective; the mystery that becomes apparent when looking at Venus in different colours.

The features of Venus' atmosphere are particularly impressive when photographs are taken using an ultraviolet or blue filter. Take the same photograph with a red filter, and the atmosphere looks a lot more boring. If you look at true-colour views of the planet, composed of red, green and blue-filter images, Venus is pretty bland.

The contrast between different parts of its atmosphere is greatest when looking at the UV part of the electromagnetic spectrum – at some points the difference in brightness is 30 to 40 per cent. In other wavelengths, these contrasts do not exist. In fact, if you were to look at Venus up close, it would be incredibly bright, yellowish white. These patches appear for a few days, but they persistently change.

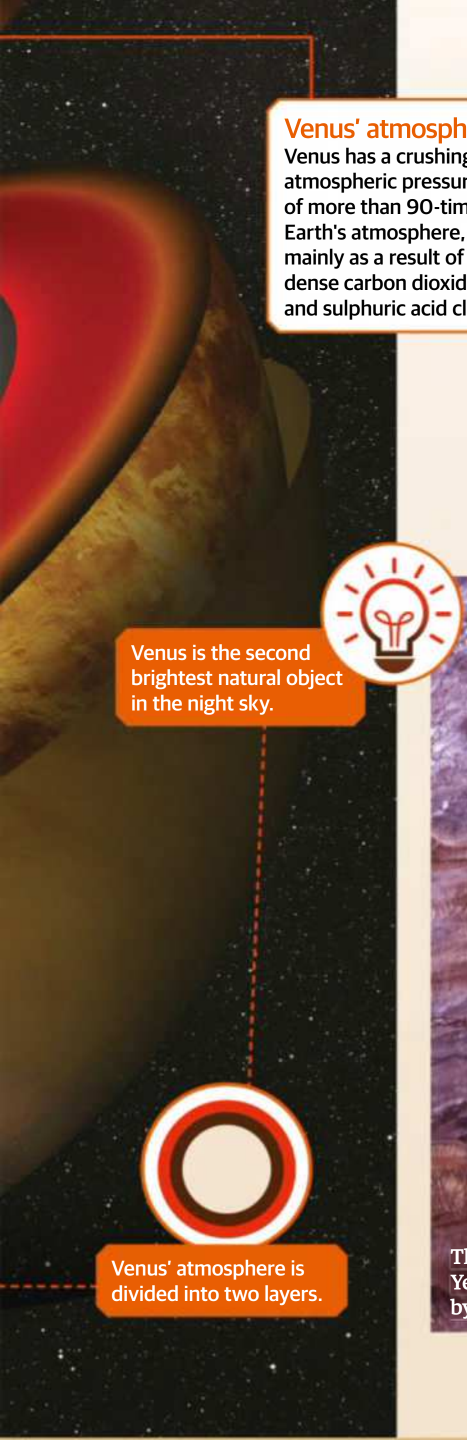
The question of why there is such a difference in brightness at particular wavelengths, and why the patches are always changing, is a bit of a mystery.

The origin of these contrasts has not been fully understood, says Limaye, who is a NASA participating scientist in the Japan Aerospace Exploration Agency's Akatsuki mission to Venus. They are thought to be related to the way sunlight shining on the atmosphere is absorbed in different wavelengths, but no theory has been able to explain it perfectly. Almost all of the theories proposed to explain the absorption have some problems, he says, whether it is in the amount, the temporal and spatial evolution or the stability.

What if, Limaye thought, the difference is caused by microorganisms in the atmosphere instead? "My reasoning was based on whether the contrasts seen in ultraviolet/blue filter images could be due to microorganisms," he says, "somewhat analogous to algae blooms in lakes."

This idea came from a chance meeting with Grzegorz Słowik of Poland's University of Zielona Góra. Słowik, who was co-author on the recent paper, told Limaye about bacteria on Earth with light-absorbing properties. These are similar to those of unidentified particles that make up unexplained dark patches observed in the clouds of Venus.

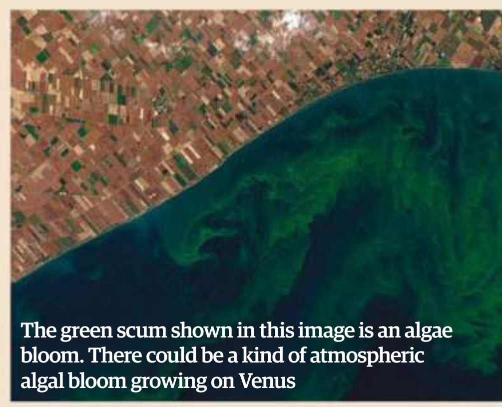
With this in mind, Limaye, Słowik and colleagues put forward the argument that these contrasts are being caused by a kind of atmospheric algal bloom in Venus. "Together, our lines of reasoning suggest that particles in Venus' lower clouds contain sufficient mass balance to harbour microorganisms,



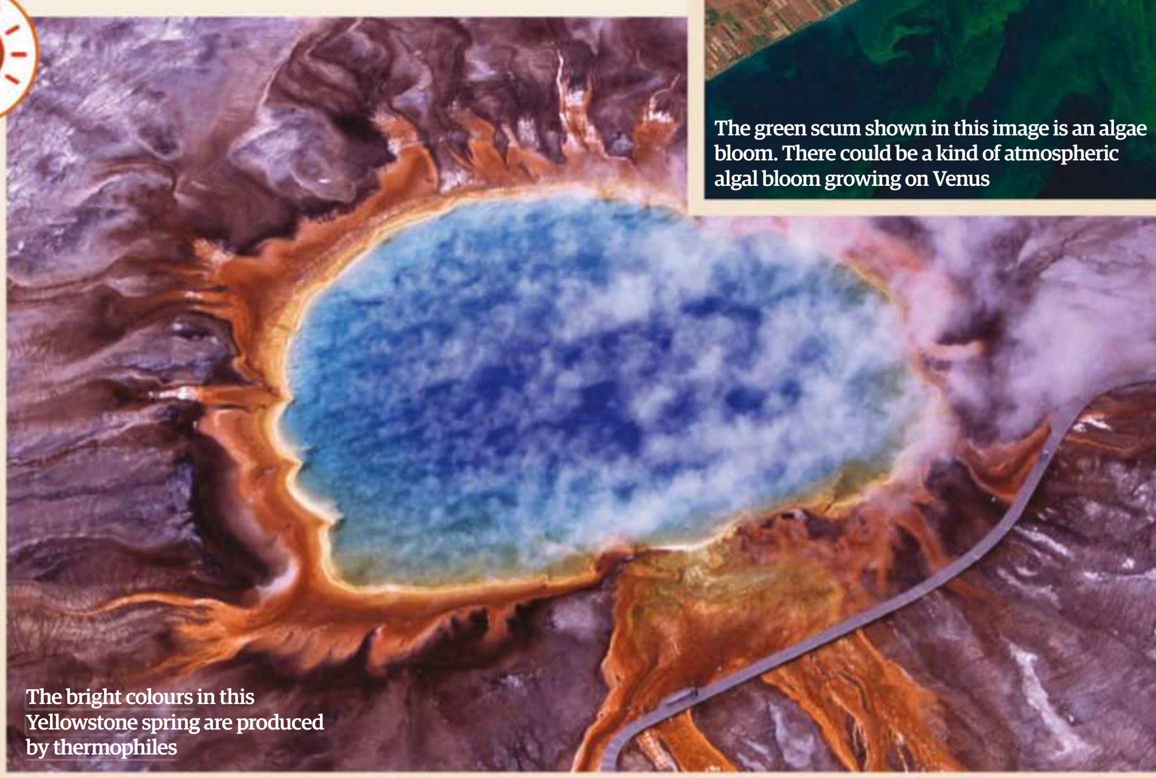
Venus' atmosphere
Venus has a crushing atmospheric pressure of more than 90-times Earth's atmosphere, mainly as a result of dense carbon dioxide gas and sulphuric acid clouds.

Venus is the second brightest natural object in the night sky.

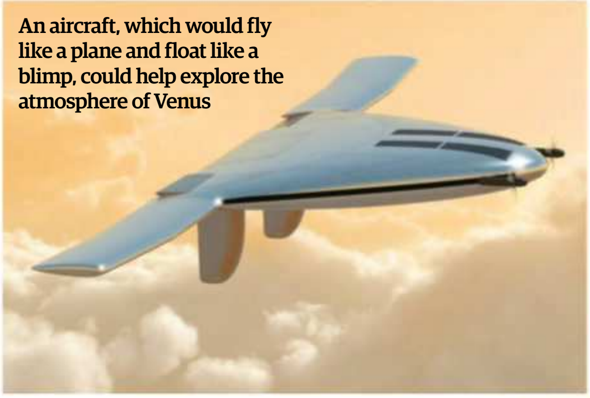
Venus' atmosphere is divided into two layers.



The green scum shown in this image is an algae bloom. There could be a kind of atmospheric algal bloom growing on Venus



The bright colours in this Yellowstone spring are produced by thermophiles



An aircraft, which would fly like a plane and float like a blimp, could help explore the atmosphere of Venus

water and solutes, and potentially sufficient biomass to be detected by optical methods," the team said in the paper. "As such, the comparisons presented in this article warrant further investigations into the prospect of biosignatures in Venus' clouds."

The physical and chemical conditions in the planet's atmosphere mean microorganisms could not only exist, but also contribute to the changing appearance of the planet's clouds, the paper says.

To investigate further, Limaye says, we need more evidence. This includes sampling the clouds of Venus for signs of life, along with laboratory studies of terrestrial microorganisms under Venus cloud-like conditions, to learn about features such as their spectral, chemical and physical properties and evolution cycles.

To inspect the atmosphere further, "balloons or instrumented drones may be possible," says Coates. "But there are broader questions to look at on Venus first, such as is there active volcanism."

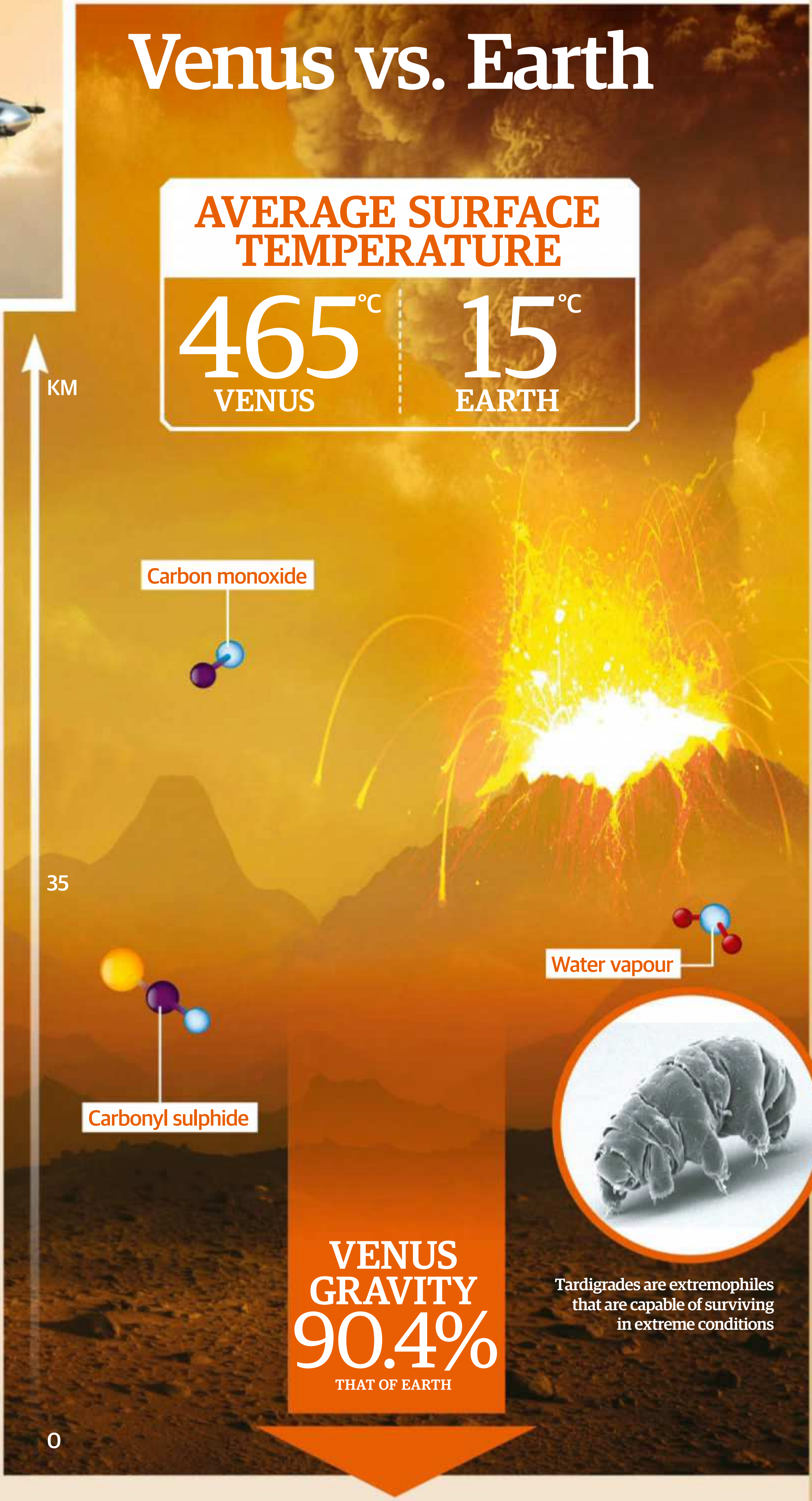
"I'm sure there will be more science missions to Venus to follow ESA's Venus Express and the Japanese Akatsuki missions, and earlier US and Russian missions," says Coates. "Understanding the atmosphere and surface more, including whether volcanism exists, are the most likely missions."

It is unlikely we will have definitive answers in the next few years. One possibility for sampling the clouds of Venus is still at the drawing-board stage.

VAMP, or Venus Atmospheric Maneuverable Platform, is a theoretical spacecraft proposed by aerospace companies Northrop Grumman and L'Garde. The vehicle would fly like a plane but float like a blimp. This would mean it could stay aloft in the planet's cloud layer for up to a year, gathering data and samples. It could carry an array of instruments, from meteorological and chemical sensors to spectrometers capable of identifying microorganisms. The companies hope VAMP could hitch a ride on board Russia's Roscosmos Venera-D mission to Venus, which is now slated for lift-off, at the earliest, in 2026.

There are ongoing discussions about possible NASA participation in the Venera-D mission. Current plans for Venera-D suggest it could include an orbiter that would be able to operate for at least three years, a lander that could survive for a few hours and potentially a NASA-built surface station and aerial platform. If this turns out to be the case, the mission could provide key information to the 50-year-old question of whether Venus' clouds could host life. Until then, we'll just have to wait and see.

Venus vs. Earth



Tardigrades are extremophiles that are capable of surviving in extreme conditions

USER MANUAL
Kepler Space Telescope

As the NASA spacecraft enters the final phase of its cosmic journey, now is a great opportunity to look back on some of its greatest achievements

THE SPECS

First light: 8 April 2009
Primary mirror size: 1.4 metres (4.6 feet)
Location: Earth-trailing orbit
Operator: NASA
Construction cost: $600 million
Time in space: Over 9 years
Distance from Earth: 94 million miles (151 million kilometres)

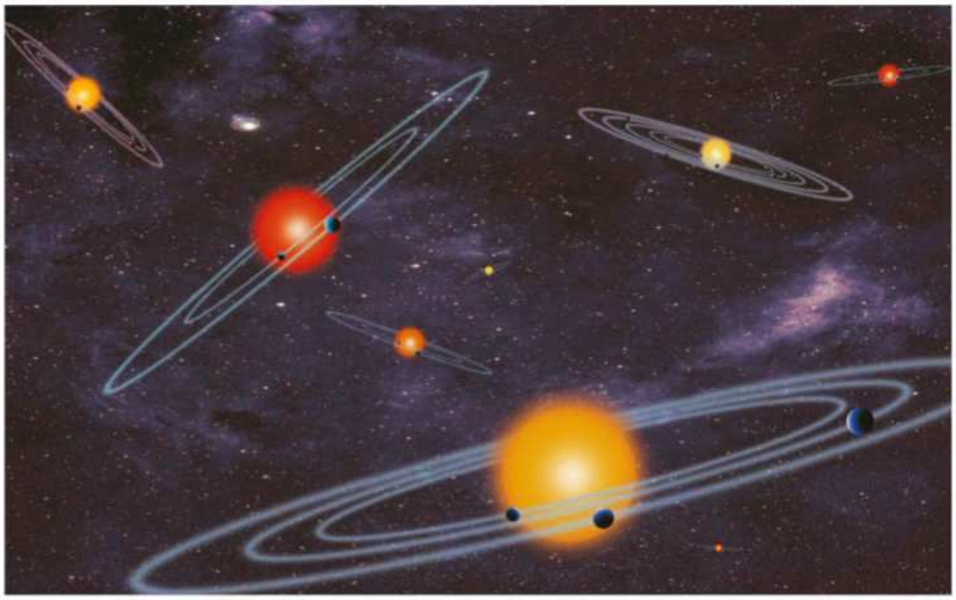
When it comes to finding new worlds beyond our own Solar System, no other telescope can compare to the amazing work completed by NASA's Kepler Space Telescope. Since its launch on 7 March 2009 (03:49:57 UTC), Kepler has spent the best part of a decade searching for a new Earth-like planet that we could someday call a new home.

Sadly, there is not much left in the tank. According to the Kepler team, fuel is scarce as Kepler is approaching its final hurdle. As the telescope trails behind Earth by 151 million kilometres (94 million miles), there is no need to use the remaining fuel to conduct a controlled demise and it can conduct scientific observations until its dying breath. While preparing for the final moments of the space telescope, now is a perfect opportunity to look back on what has been a marvellous mission.

Kepler became the tenth member of NASA's Discovery mission when it blasted off from Cape Canaveral Air Force Station in Florida, United States. The aim of this mission was clear: find a new Earth. By watching a patch of the sky which covers just 0.25 per cent of the entire sky, equating to 115 square degrees between the constellations Cygnus and Lyra, scientists were searching for Earth-sized planets orbiting within their host stars' habitable zones - the region around a star where water could theoretically exist as a liquid. Kepler also searched for larger planets too, the majority of which have been between Earth- and Neptune-sized (which itself is almost four-times the size of the Earth).

By detecting these planets, scientists can determine a range of physical and orbital aspects of the distant stellar systems, including the size, reflectivity, mass and density of the exoplanets, as well as how long the orbit takes and if there are any other planets lurking in the same system. If our Solar System can hold eight planets, why can't that be the case for other star systems? This combination of aims and goals led the Kepler scientists to explore what is out there and has helped transform the idea of multiple habitable worlds existing beyond Earth from science fiction into a reality.

For almost four years the Kepler mission watched over the same patch of sky. Within this period the primary Kepler mission discovered 2,327 confirmed exoplanets, with a further 2,244 candidates. The first five exoplanets were announced in January 2010, bringing the likes of Kepler 4b, 5b, 6b, 7b and 8b to the public eye. All five of these exoplanets

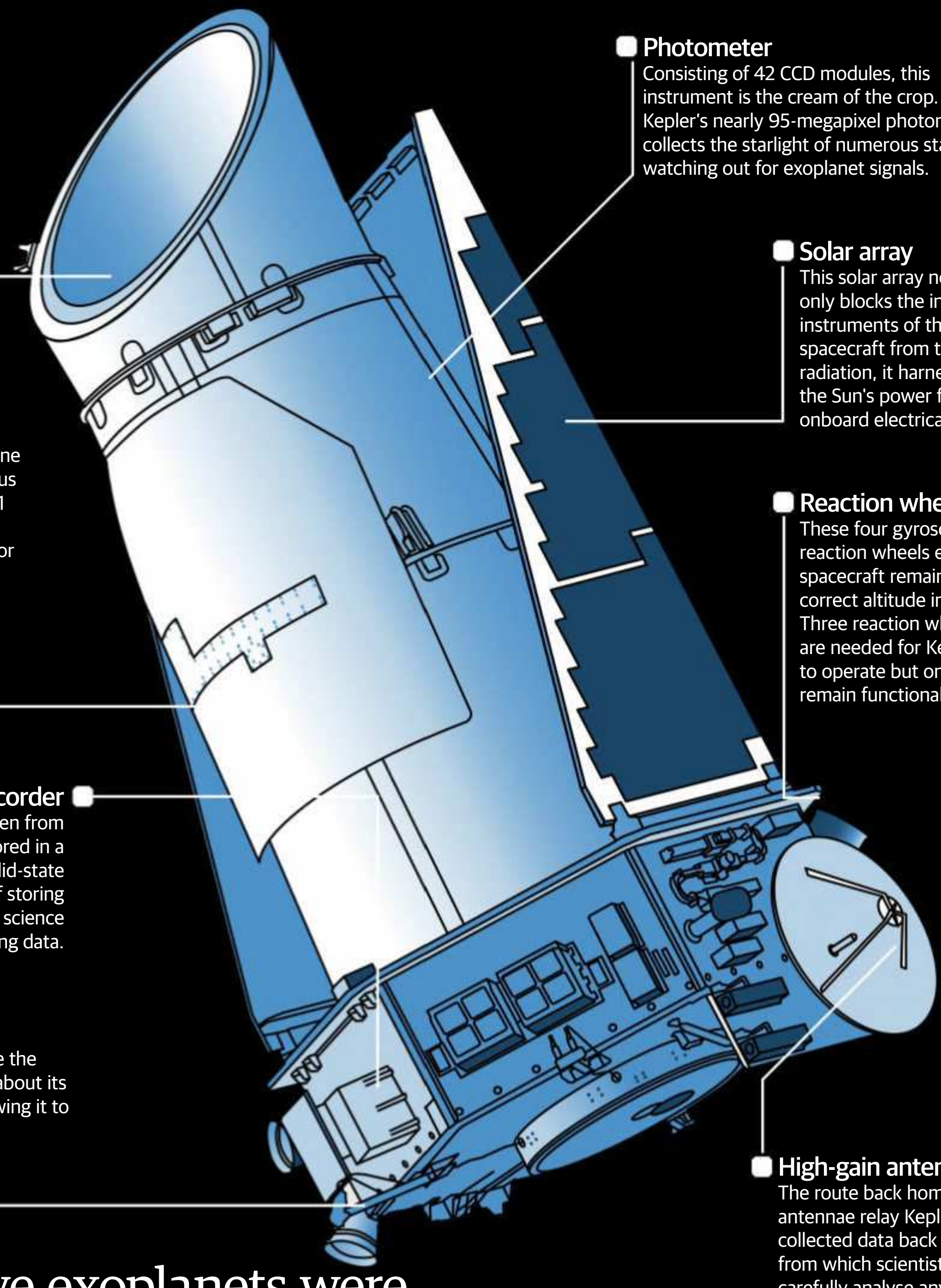


Observing exoplanets via the transit method relies on our viewing orientation, as it is vital that the planet passes in front of the star, blocking out some of its light

Kepler was launched aboard a Delta II rocket and has found 30 Earth-like exoplanets in the habitable zone

Anatomy of the Kepler Space Telescope

These instruments provide optimal starlight-capturing capabilities, allowing astronomers to uncover thousands of exoplanets over a period of nine years



Sunshade
Mounted on the front of Kepler is its sunshade. As the name suggests it prevents sunlight from entering the photometer, allowing for uncontaminated observations.

Photometer
Consisting of 42 CCD modules, this instrument is the cream of the crop. Kepler's nearly 95-megapixel photometer collects the starlight of numerous stars, watching out for exoplanet signals.

Solar array
This solar array not only blocks the internal instruments of the spacecraft from the Sun's radiation, it harnesses the Sun's power for all its onboard electrical systems.

Radiator
In order to keep the focal plane cooled to approximately minus 85 degrees Celsius (minus 121 degrees Fahrenheit), heat is carried to the external radiator by a series of pipes.

Reaction wheels
These four gyroscope-like reaction wheels ensure the spacecraft remains at the correct altitude in space. Three reaction wheels are needed for Kepler to operate but only two remain functional.

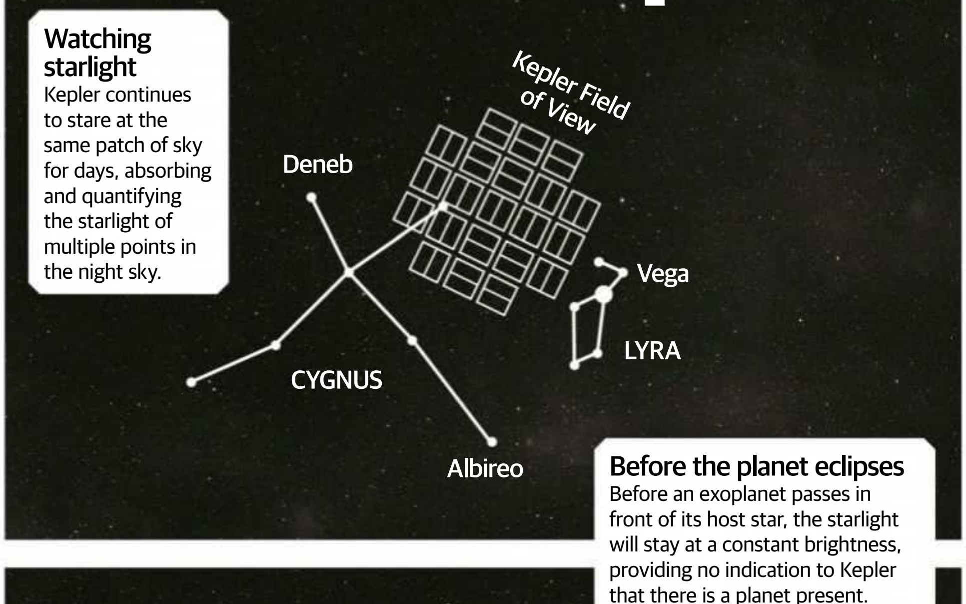
Solid-state recorder
All the data taken from Kepler is stored in a 16 gigabyte solid-state recorder, capable of storing 60 days worth of science and engineering data.

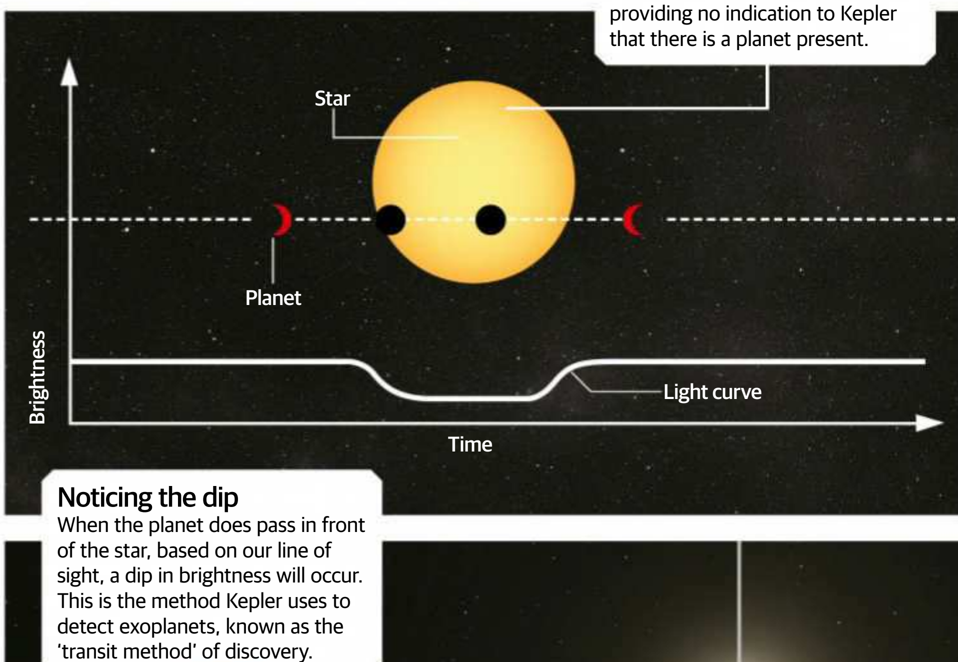
Star trackers
The two star trackers provide the spacecraft with information about its current inertial attitude, allowing it to orient itself in deep space.

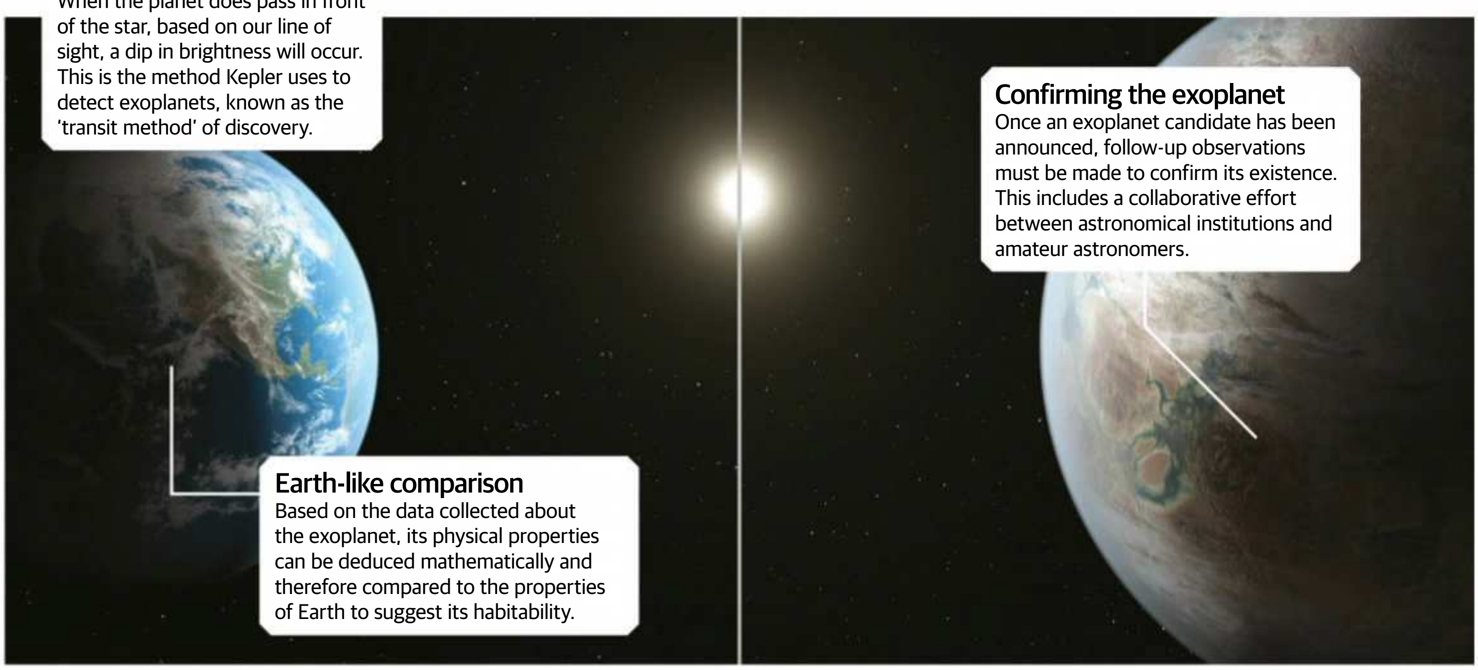
High-gain antenna
The route back home. These antennae relay Kepler's collected data back to Earth, from which scientists can carefully analyse any signals.

"The first five exoplanets were announced in January 2010"

How to... Find an exoplanet





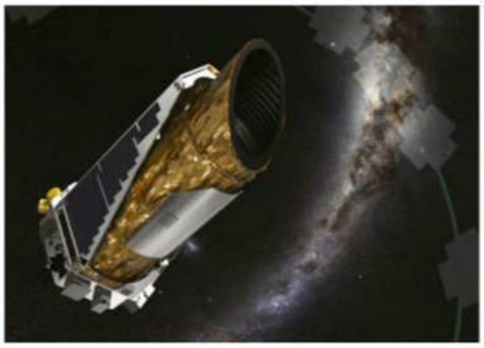


> "If our Solar System can hold eight planets, why can't that be the case for other star systems?"

were designated 'hot Jupiters', as they range in size from similar to Neptune to larger than Jupiter, but have orbits ranging between 3.3 and 4.9 days. Researchers estimated the temperature of the planets to range from 1,204 to 1,649 degrees Celsius (2,200 to 3,000 degrees Fahrenheit); all exoplanets orbit stars hotter and larger than our star.

Discoveries such as these became the norm in the years to follow. Then worry struck Kepler's engineers in July 2012, when one of the reaction wheels failed. With the other three still intact, Kepler was still able to maintain its fixed field of view in order to search for more exoplanets. But in May 2013, engineers received the unfortunate news that a second reaction wheel had also failed. This brought the primary mission of Kepler, which had exceeded expectations by six months, to an end.

This was not the end of the Kepler Space Telescope though, thanks to the innovative and intelligent thinking of Kepler's scientists and engineers. By using the two remaining reaction wheels and the solar pressure, Kepler is capable of stabilising to one field of view for approximately 80 days before having to change its sights to a different location. Each new section of the night sky that Kepler is watching is known as a 'campaign', and scientists estimated that Kepler only had ten campaigns left in it. Yet again Kepler has gone above and beyond, entering campaign number 18 on 12 May 2018. Rebranded 'K2', this mission



continues to provide valuable data to us and has boosted the number of confirmed exoplanets, so far, by a further 292 planets.

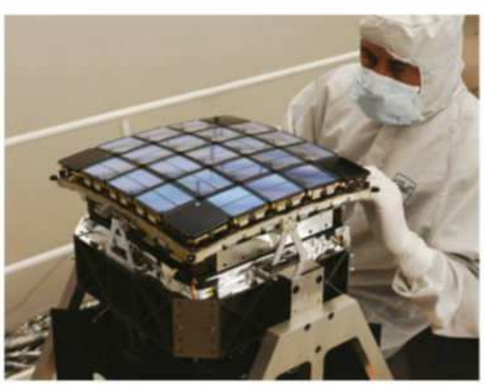
The day when Kepler ceases to function is not far off, unfortunately. At the time of writing, the Kepler team announced that within a few months the Kepler Space Telescope will run out of fuel and shut down permanently. So, as the hardy spacecraft races towards the finish line, it will bring a close to the most successful planet-hunting mission in history. Not to worry though - in April 2018, NASA launched a brand-new spacecraft that has the same goal in mind: find a new Earth. The Transiting Exoplanet Survey Satellite (TESS) is the first space-based all-sky transit survey that will monitor a sky area that is 400-times larger than Kepler and study stars that are 30 to 100 times brighter. Only through a collaborative effort will astronomers find a diamond in the rough, and discover Earth 2.0.

TOP TECH

Kepler's photometer

The main instrument is a Schmidt telescope with a 0.95-metre (3.1-feet) mirror, which collects data about starlight; it does not take conventional pictures. Although this is a simple single-purpose design, this photometer has performed a magnificent job of gathering each speck of light for the last nine years. Overall, the photometer is comprised of 42 charged-coupled devices (CCDs), each of which has an array of 2,200x1,024 pixels.

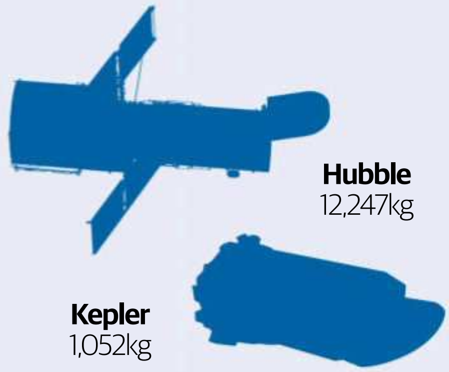
The CCDs provide a read out every six seconds, which prevents the instrument from going over its maximum charge capacity, also known as 'saturation'. This data is transmitted back to Earth once a month via NASA's Deep Space Network.



Head to head
Kepler vs Hubble

Because of its more extensive light-capturing capabilities, Hubble can make vague estimations of an exoplanet's atmosphere. This is due to Hubble's ability to capture near-infrared, visible and ultraviolet light, unlike Kepler's extremely narrow wavelength band of 430-890 nanometres.

When you compare their size and mass, Hubble is grander in every way. Hubble is 8.6 metres (28.2 feet) longer, 11,195 kilograms (24,681 pounds) heavier and the primary mirror is 1-metre (3.28 feet) larger, which provides a collecting area that is 3.79 metres squared (41 square feet) larger.



Vital statistics

4.7 metres high = Roughly the same length as a large family car

1,052kg The total mass at launch = Almost four-times a male grizzly

1.4 mtr The primary mirror size = Five-times smaller than JWST

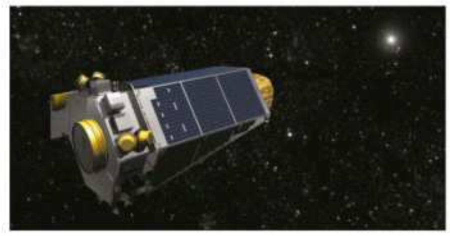
94 *million miles* = That's 3,770 laps around the Earth!

3,000 *light years* The farthest stars detectable by Kepler = 705-times further away than Proxima Centauri

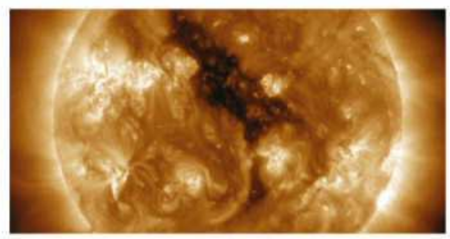
HOW TO...

Revive Kepler

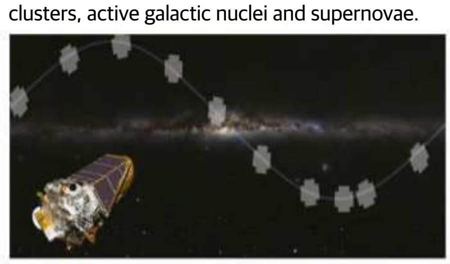
1 Identifying the problem
When the Kepler Space Telescope enters its thruster-controlled Safe Mode, engineers know there must be something wrong. After analysing the situation, engineers determined there was an attitude error, and it can be traced back to one of the reaction wheels malfunctioning.



2 Solar solution
With the correct positioning, the spacecraft's solar panels can protect the instrumentation while creating a stable balance for approximately 83 days. The mission was rebranded as 'K2', bringing it a new lease of life.



3 Switching targets
After 83 days Kepler will start looking at a different patch of sky, known as a 'campaign'. During campaign 1, Kepler collected data of more than 12,000 target stars as well as observing star clusters, active galactic nuclei and supernovae.

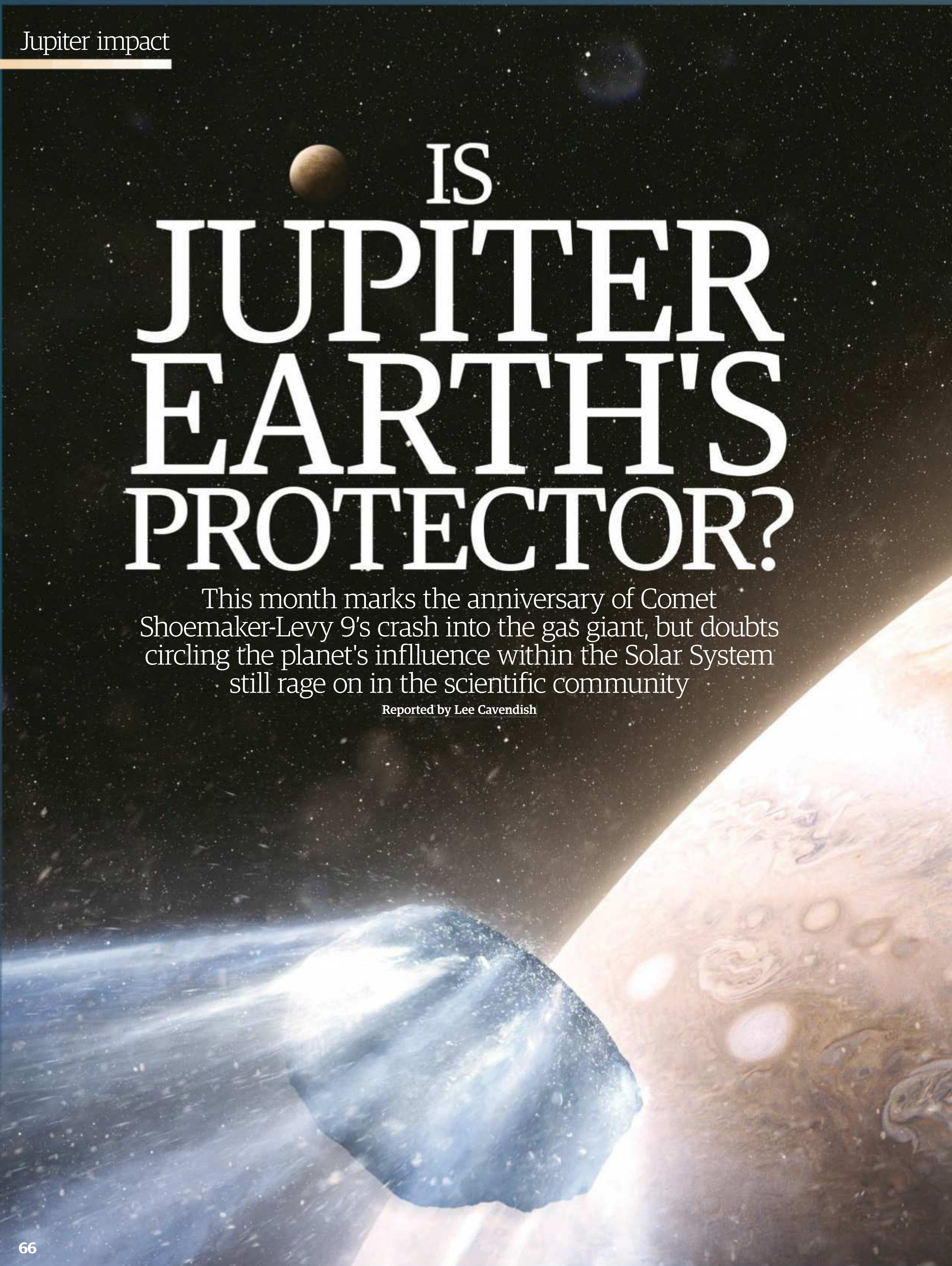


4 Finding new candidates
Although Kepler cannot stay on a fixed position as long as it used to, there is still the opportunity for discovery of short-period exoplanets. The K2 mission has, so far, 480 candidate and 292 confirmed extrasolar planets.

IS JUPITER EARTH'S PROTECTOR?

This month marks the anniversary of Comet Shoemaker-Levy 9's crash into the gas giant, but doubts circling the planet's inflluence within the Solar System still rage on in the scientific community

Reported by Lee Cavendish



© Tobias Roetsch

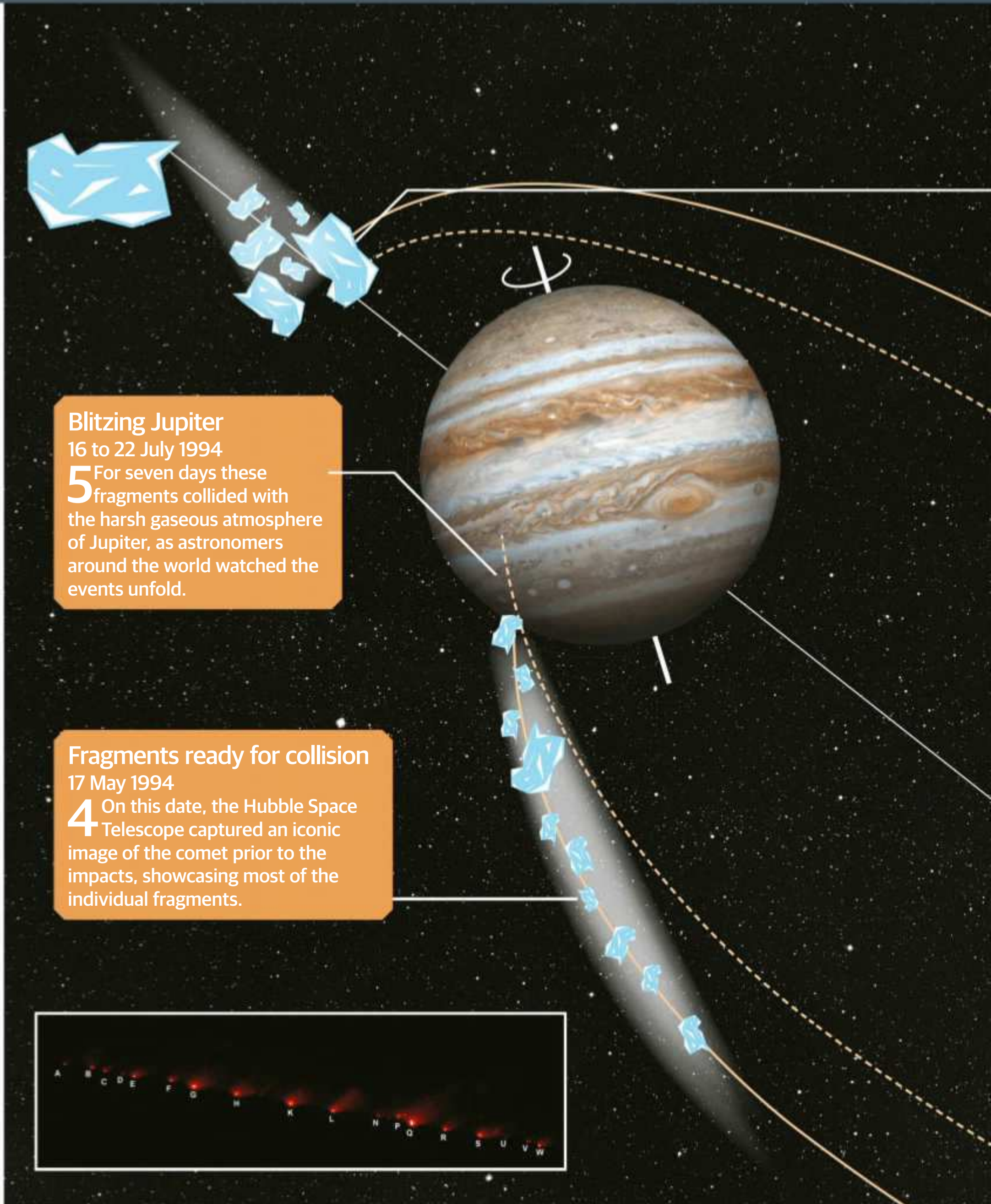
"I have been observing and studying comets ever since I was a child. I never actually thought of the idea that comets could collide with a planet with such an effect. Shoemaker-Levy 9 taught us the basic lesson that comets hit planets and they have dramatic effects," David Levy, one of the three discoverers of the Shoemaker-Levy 9 comet, along with Carolyn and Eugene Shoemaker, tells **All About Space**. The comet collided with the largest planet in our Solar System with enough force to cover it in visible scars for months after; it was a truly awe-inspiring event. It brought global attention to near-Earth objects (NEOs), notably how Jupiter can manipulate these objects for good or bad.

July 2018 marks the 24th anniversary of Comet Shoemaker-Levy 9 crashing and disintegrating into the tempestuous atmosphere of Jupiter. This was the first time astronomers were able to observe an extraterrestrial impact between a comet and a planet. For months, scientists knew this comet was caught in the orbit of Jupiter and would eventually be torn apart by the extreme gravity of the gas giant, but more importantly it was on a collision course heading straight for Jupiter.

When asked about the lead-up to the event, Levy replies: "We knew as soon as we found out that there was going to be a collision (we found that out on 22 May 1993) that this would be a historic comet. But right away everybody started squealing and yelling that we wouldn't see anything, you know, it would be a dud because things hit [Jupiter] all the time and we never see anything."

How the doubters were wrong. Over a period of seven days, 21 fragments of the dying comet peppered the atmosphere of Jupiter. These fragments released a tremendous amount of energy upon each impact – the first fragment alone struck the gas giant's atmosphere with enough kinetic energy to equate to 225,000 megatons of TNT. This impact produced plumes made up of Jovian and cometary ingredients about 1,000 kilometres (621 miles) above the cloudtops. To put this into context, the atomic bomb 'Fat Man' that was dropped on Nagasaki, Japan in World War II was the equivalent of just 0.02 megatons of TNT.

A series of impacts of such magnitude was an event astronomers refused to miss, so when 16 July 1994 rolled around, a worldwide audience of ground-based and space telescopes watched the cataclysmic event unfold. This was an extremely rare opportunity to take a peek through the gaseous



Preparing to strike a planetary king:
The timeline of a dying comet

From its discovery to its disentegration into Jovian plumes, the frozen object's course was tracked from around the world

Fragment impact times

Fragment: A
Date: 16 July 1994
Time (UTC): 20:11

Fragment: B
Date: 17 July 1994
Time (UTC): 02:50

Fragment: C
Date: 17 July 1994
Time (UTC): 07:12

Fragment: D
Date: 17 July 1994
Time (UTC): 11:54

Fragment: E
Date: 17 July 1994
Time (UTC): 15:11

Fragment: F
Date: 18 July 1994
Time (UTC): 00:33

Fragment: G
Date: 18 July 1994
Time (UTC): 07:32

Fragment: H
Date: 18 July 1994
Time (UTC): 19:32

Fragment: K
Date: 19 July 1994
Time (UTC): 10:21

Fragment: L
Date: 19 July 1994
Time (UTC): 22:17

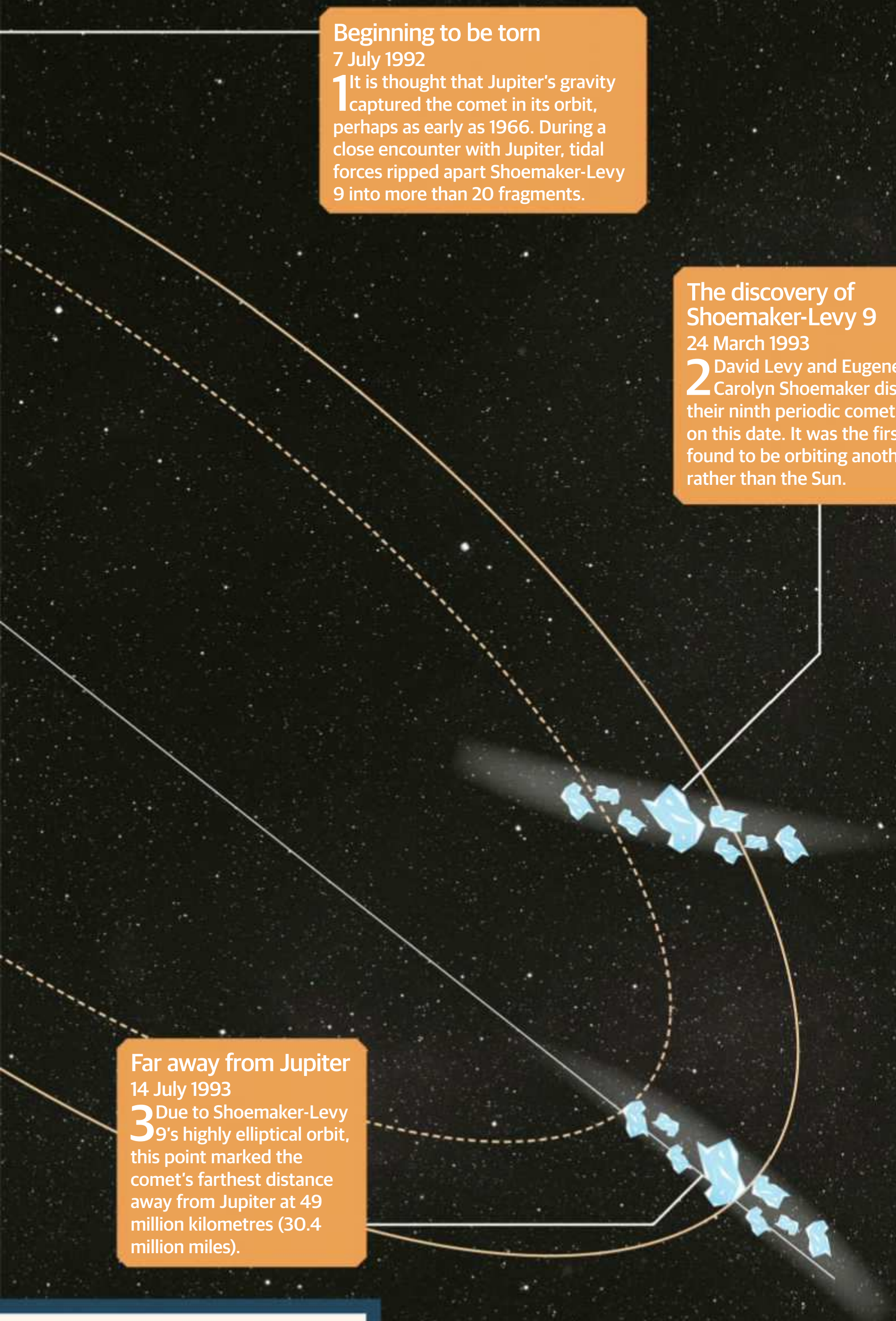
Fragment: N
Date: 20 July 1994
Time (UTC): 10:31

Fragment: P
Date: 20 July 1994
Time (UTC): 15:23

Fragment: Q
Date: 20 July 1994
Time (UTC): 19:44

Fragment: R
Date: 21 July 1994
Time (UTC): 05:33

Fragment: S
Date: 21 July 1994
Time (UTC): 15:15



Beginning to be torn
7 July 1992

1 It is thought that Jupiter's gravity captured the comet in its orbit, perhaps as early as 1966. During a close encounter with Jupiter, tidal forces ripped apart Shoemaker-Levy 9 into more than 20 fragments.

The discovery of Shoemaker-Levy 9
24 March 1993

2 David Levy and Eugene and Carolyn Shoemaker discovered their ninth periodic comet together on this date. It was the first comet found to be orbiting another planet rather than the Sun.

Far away from Jupiter
14 July 1993

3 Due to Shoemaker-Levy 9's highly elliptical orbit, this point marked the comet's farthest distance away from Jupiter at 49 million kilometres (30.4 million miles).

Fragment: U
Date: 21 July 1994
Time (UTC): 21:55

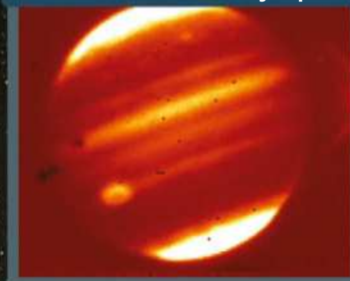
Fragment: V
Date: 22 July 1994
Time (UTC): 04:22

Fragment: W
Date: 22 July 1994
Time (UTC): 08:05

"Shoemaker-Levy 9 taught us the lesson that comets hit planets and they have dramatic effects" **David Levy**

Eyes on the impacts

Calar Alto Observatory, Spain



Hubble Space Telescope

Siding Spring Observatory, Australia

Galileo spacecraft

NASA Infrared Telescope Facility, Mauna Kea, Hawaii

atmosphere of Jupiter and see what's underneath. Although the impacts occurred on the face of Jupiter that faces away from Earth, the lingering scars would eventually reveal themselves to Earth.

Watching Jupiter as it was being continuously struck with huge lumps of space rock and ice, resulting in spectacular upheaval, brought a real sense of humility. It made everybody think about the role Jupiter plays in comet and asteroid trajectories in relation to Earth. Jupiter is the largest body in the Solar System, being nearly 11-times larger than Earth in size and also over 317-times more massive. So with a much greater gravitational pull, Jupiter could potentially catapult comets and asteroids anywhere, even towards Earth.

A few months before the Shoemaker-Levy 9 comet impact, a planetary scientist called George Wetherill conducted a series of simulations that suggested that Jupiter, with the help of Saturn, helped clear out the inner Solar System from potential impactors, as their combined gravity slingshots these objects away from our home planet.

The daunting idea of an asteroid or comet breaking through Earth's atmosphere and hitting the ground, releasing a tremendous shockwave that will shake the world is a constantly looming thought. About 66 million years ago, 80 per cent of all species living on Earth were suddenly wiped out, signalling the end of the dinosaurs' time period. This event is known as the Cretaceous-Tertiary mass extinction event, but better known as the K-T event. Although there is no confirmation of what caused this event, the best explanation for this mass extinction is the impact of a ten-kilometre (six-mile) asteroid hitting the Earth.

By combining the work that suggests Jupiter removes potential impacts, the observed Shoemaker-Levy 9 comet impact and the gnawing idea that an asteroid or comet with great mass could cause a mass extinction on Earth, the notion that Jupiter is our 'planetary protector' was born. If this were a game of cosmic football, then Jupiter would be the goalkeeper. If any ball – in this case, one made out of rock and ices – came this way, Jupiter would send it flying away with elegance comparable to René Higuita's famous 'Scorpion Kick' save against England in 1995. This is why people thought, and most probably still think, that Jupiter is essential for life on Earth. With Jupiter redirecting any potential troublemakers, this allowed life to evolve peacefully and prosper.

For decades, this was a popular concept promoted by the media and other authorities. However, in the last few years there has been extensive research into the matter, and this concept has come heavily under fire. Dr Kevin Grazier, assistant professor at the United States Military Academy's Department of Computer Sciences at West Point, New York, speaks to **All About Space** about his own simulations that put this hypothesis under the microscope.

"I recreated Wetherill's simulations with modern, and much more accurate numerical methods, and found that while it is true that Jupiter and Saturn did largely eliminate the planetesimals that orbited between them from the Solar System – or, at least, kicked them out to great distances – many of those passed through the inner Solar System during that evolution," says Grazier. "A low-inclination comet that passes close to Jupiter today is equally likely to be diverted towards Earth as away."

So not only is it arguable that Jupiter diverts comets and asteroids away from Earth, but there is also the strong case that it does the opposite. If we look at the case of Comet D/1770 L1, or Lexell's comet, it presents a fine case for exactly that. On 1 July 1770 the comet passed the Earth at a distance of only 2.2 million kilometres (1.4 million miles) – the closest approach of a comet to the Earth and the first recorded NEO. After its discovery and its close encounter the orbit of the comet was traced back, a very interesting aspect of the orbit was revealed. Three years prior to the close encounter, it appears the gravitational forces of Jupiter made a distinctive change to the comet's trajectory, sending

"Jupiter and Saturn played key roles in delivering volatile-laden planetesimals to the inner Solar System" **Dr Kevin Grazier**

Hubble was able to observe the aftermath of the 1994 and 2009 Jupiter impacts

© NASA JPL-Caltech; ESA; Ian Sharp, SSO Australia

it extremely close to Earth. This begs the question, what if it crashed into Earth?

Depending on the size of the comet, with recent studies suggesting the nucleus of the comet was roughly ten kilometres (6.2 miles) in diameter, the potential destruction wouldn't have been good. Astronomers also argue that if a cometary impact hadn't happened a few billion years ago, then Earth as we know it could have been a barren world.

"Jupiter and, to some extent, Saturn played key roles in delivering volatile-laden planetesimals - objects having large amounts of ices like water, carbon dioxide, methane and ammonia - to the inner Solar System," explains Grazier. "These are the compounds that formed Earth's early atmosphere and, later, its hydrosphere and biosphere. Without these compounds, the emergence of life on Earth may have been far less likely." If Jupiter had sent a comet Earth-bound in the early ages of the Solar System, that could have lead to what we have now.

What is known now is that comets and asteroids will forever be a potential threat, and the Solar System is cluttered with them, with most hiding away in the darkness of space. This is why a new series of organisations were formed dedicated to the monitoring of NEOs, with NASA starting up the NEO Observations Program in 1998. In 1998, a congressional directive founded this programme with the aim to discover at least 90 per cent of one kilometre diameter or larger NEOs within 10 years, which was finally met in 2010. Grazier thinks that Shoemaker-Levy 9 was influential in the making of programmes such as these, as he goes on to say:

Analysis of Rosetta's Comet 67P/ Churyumov-Gerasimenko has shown it to contain lots of volatiles

Asteroids vs Comets

These two types of NEOs could crash into any planet, but they differ in a variety of aspects

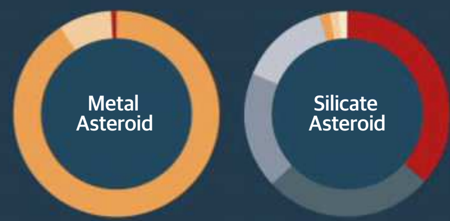
IDENTIFICATION

Asteroids

These types of space rocks are composed primarily of silicates, metals or a combination of the two.

Comets

Comets mainly contain ices with smaller amounts of rock and dust. They form a coma and a tail.



Iron 91% Nickel 8.5% Cobalt 0.06%

Oxygen 36% Iron 26% Silicon 18% Magnesium 14% Aluminium 1.5% Nickel 1.4% Calcium 1.3%

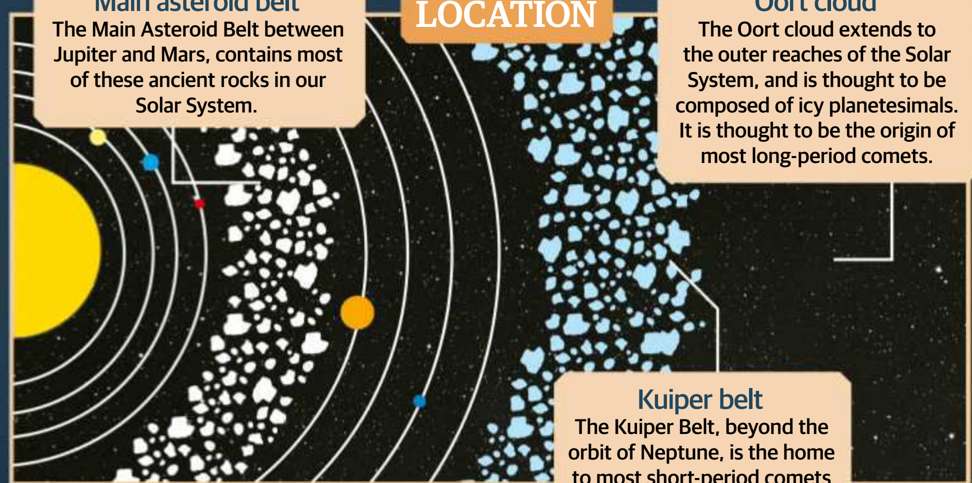
LOCATION

Main asteroid belt

The Main Asteroid Belt between Jupiter and Mars, contains most of these ancient rocks in our Solar System.

Oort cloud

The Oort cloud extends to the outer reaches of the Solar System, and is thought to be composed of icy planetesimals. It is thought to be the origin of most long-period comets.



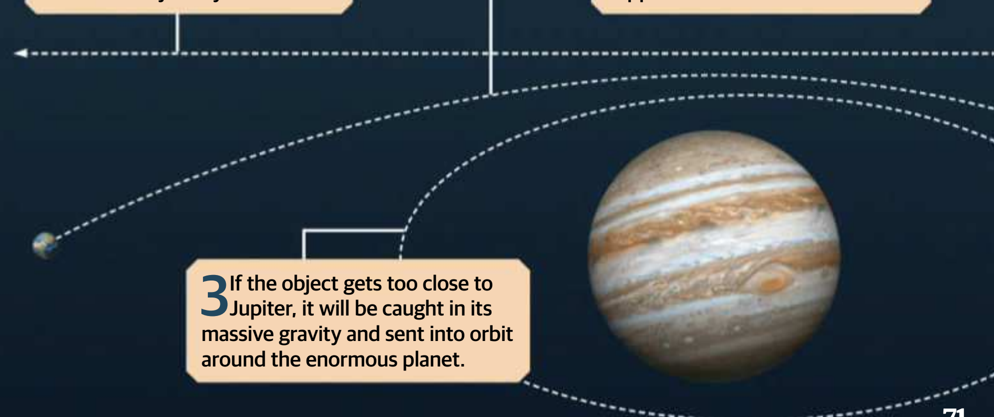
Kuiper belt

The Kuiper Belt, beyond the orbit of Neptune, is the home to most short-period comets in the Solar System.

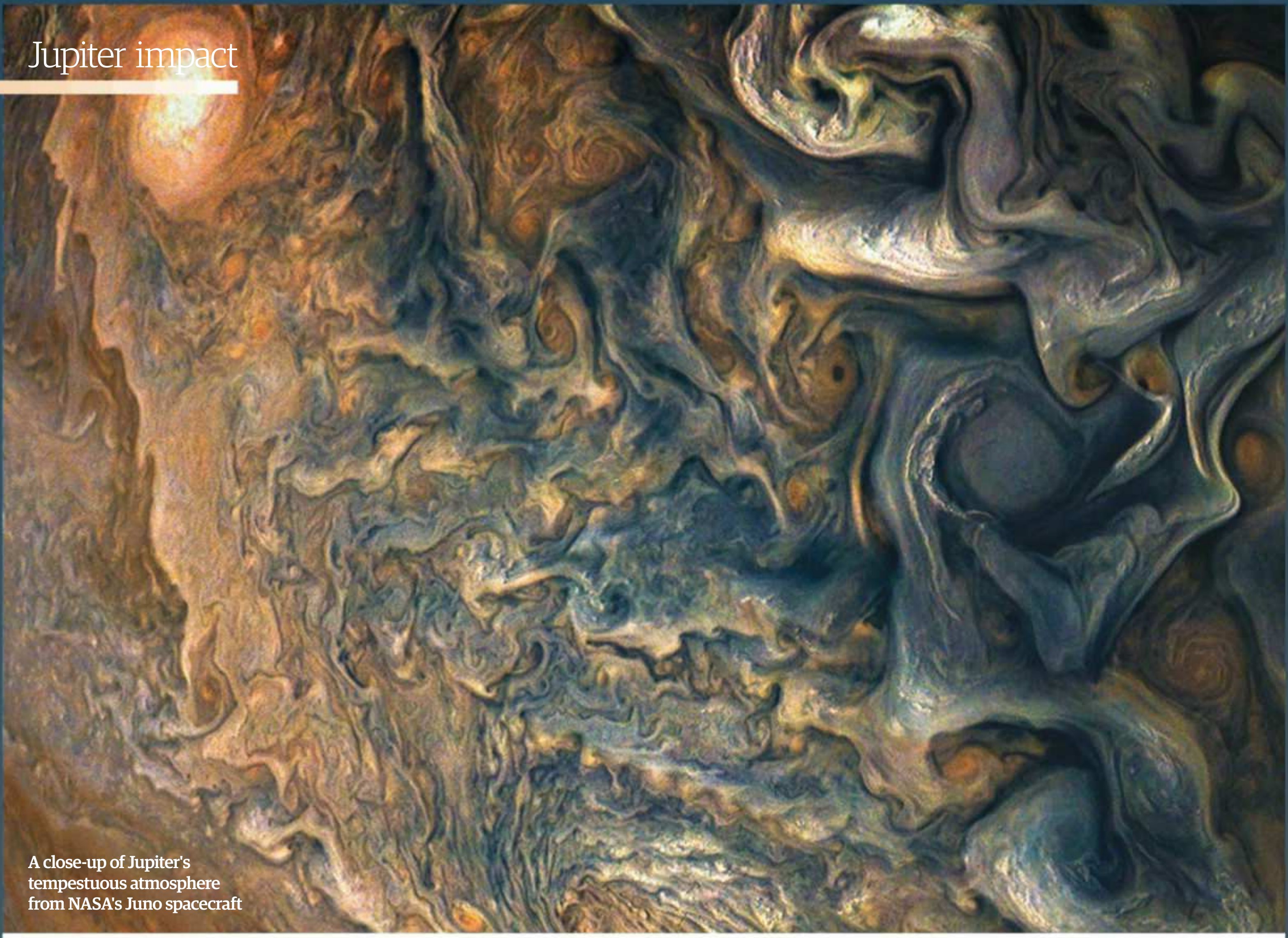
ALTERING ORBITS

1 If the object is far enough away from Jupiter so that it cannot be affected by the gas giant's gravity, it will continue on its normal trajectory.

2 In an unlikely, yet possible, scenario Jupiter can change an object's trajectory for it to head towards Earth, which is what happened with Lexell's comet.



3 If the object gets too close to Jupiter, it will be caught in its massive gravity and sent into orbit around the enormous planet.



A close-up of Jupiter's tempestuous atmosphere from NASA's Juno spacecraft

"I do think SL9's impact into Jupiter was a very dramatic opportunity to sell people outside of these fields on the reasons why we feel we need to survey the skies to find and categorise as many small bodies in the Solar System as we possibly can."

Professional surveys aren't the only way to find NEOs, and the long-standing art of amateur astronomy is still a keen player in monitoring NEOs and other important events throughout the universe. Much like David Levy and Eugene and Carolyn Shoemaker, the persistence of amateur astronomy will continue to reap benefits for the astronomical community. One significant event that exemplifies this occurred in July 2009, when an amateur astronomer called Anthony Wesley discovered a dark and deep scar on the face of Jupiter's southern polar region.

"A low-inclination comet that passes close to Jupiter today is equally likely to be diverted towards Earth as away" **Kevin Grazier**

Wesley reveals to **All About Space** about the night of his discovery. "I kept recording video for another couple of hours. As this feature came further into view and I could see a clearer image, then it seemed more and more likely that I was seeing the after-effect of a large impact on Jupiter from some unknown object," says Wesley. "I sent an email alert out to my mailing list that contained both amateur astronomers and professionals."

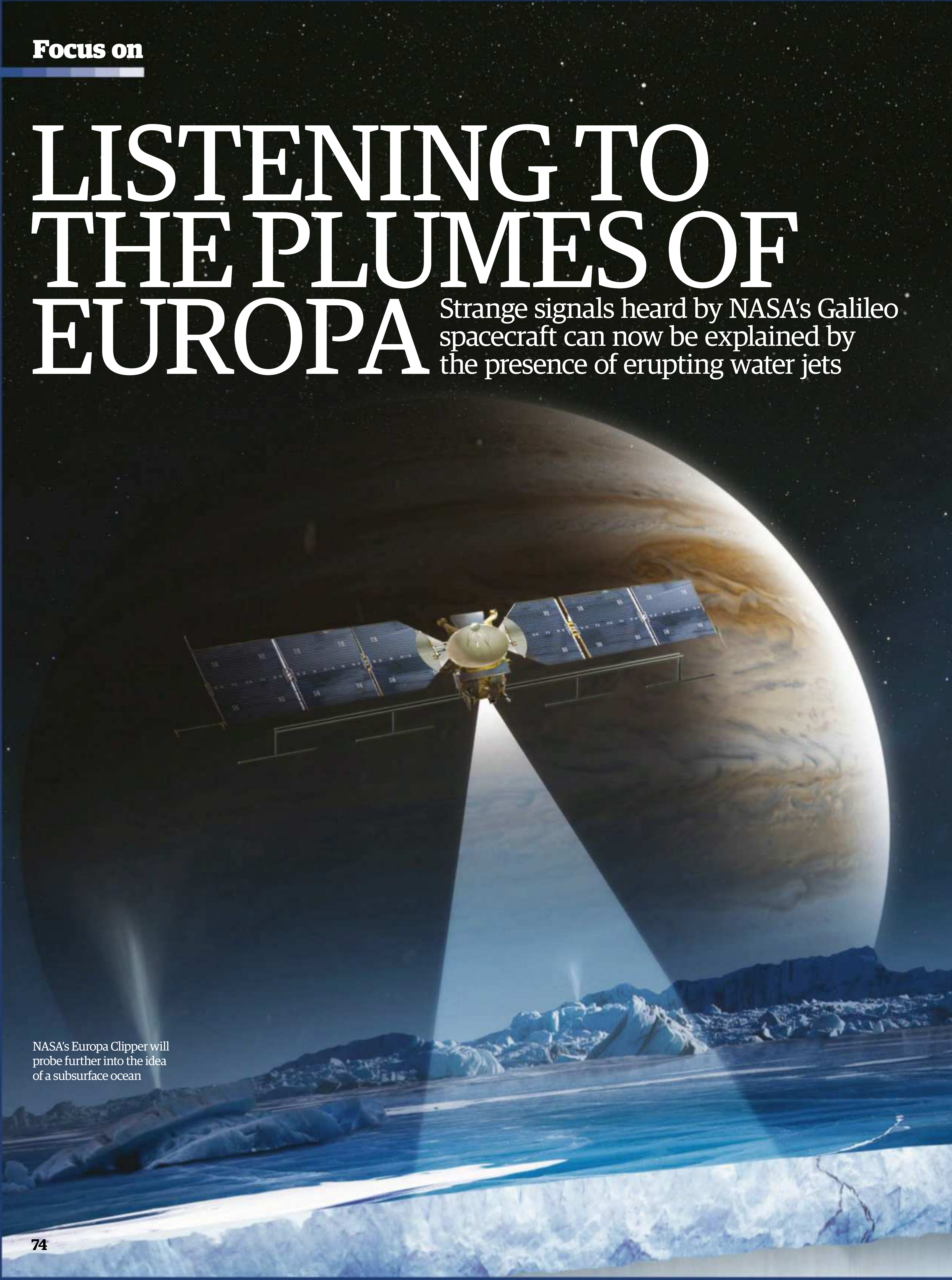
Cometary impacts with a young Earth could have brought about life as we know it

© NASA JPL-Caltech

Obviously any discovery needs professional confirmation, but the continual observation is what led to this magnificent discovery of a scar on Jupiter, which was later described as an aftermath effect of a collision from either a comet or an asteroid. Astronomers were able to use the Hubble Space Telescope's brand-new Wide Field Camera 3 to compare the damage with that caused by Shoemaker-Levy 9. The 2009 impact showed a lack of fine particles, and the scar disappeared more quickly – over three weeks – suggesting the object contained heavier material and sunk swifter into Jupiter. These observations and comparisons led astronomers to believe the 2009 impact was the result of a more solid, asteroidal body rather than a comet like Shoemaker-Levy 9. With further observations, one day we may be able to unravel the mystery of Jupiter and its influence on the Solar System. In the space of almost a quarter of a century, Jupiter has gone from Earth's protector to the instigator for collisions. This research may not have been possible without the exposure of Comet Shoemaker-Levy 9, which made the scientific community pay more attention to the mysterious NEOs that permeate circumsolar space.

LISTENING TO THE PLUMES OF EUROPA

Strange signals heard by NASA's Galileo spacecraft can now be explained by the presence of erupting water jets



NASA's Europa Clipper will probe further into the idea of a subsurface ocean

Data dated at 20 years old and gathered by a now-defunct NASA spacecraft has shed new light on Jupiter's smallest Galilean moon, Europa. While delving into the archives from the Galileo probe, astronomers discovered evidence that the craft flew through a plume of water erupting from Europa's icy surface. The recent research provides a compelling case for the long-standing theory that beneath the moon's frozen crust is a subsurface ocean with the ingredients to support life.

Much like when the Cassini mission discovered plumes erupting from the surface of Saturn's moon Enceladus, the Galileo spacecraft fortuitously found the same thing as it made its way past Europa. With the help of advanced computer models astronomers have been able to explain a brief, localised tangle in the magnetic field that was previously a bit of an enigma. When the Hubble Space Telescope observed Europa in 2012 using its ultraviolet capabilities there was the suggestion of water plumes erupting from the frigid south-pole region. With this new analysis researchers are getting closer to the highly anticipated source.

The inspiration to go back to the old data came from when Xianzhe Jia, a space physicist at the University of Michigan in Ann Arbor, United States, went to a presentation by Melissa McGrath. McGrath, of the SETI Institute in Mountain View, California, spoke about when Hubble took a look at Europa six years ago. "One of the locations she mentioned rang a bell. Galileo actually did a flyby of that location, and it was the closest one we ever had. We realised we had to go back," says Jia. "We needed to see whether there was anything in the data that could tell us whether or not a plume existed or not."

At the time of Galileo's flyby of Europa in 1997, the spacecraft flew just 200 kilometres (124 miles) above the surface, and the team weren't even aware of the possibility that it had just steered through a plume of water vapour. Upon re-examination, it appears that there was a strange reading by the high-resolution magnetometer. Researchers have been able to compare the mysterious signals from Galileo with the more recent results of Cassini's analysis of Enceladus' plumes. Cassini was able to deduce that material in the plumes had become ionised, hence leaving a recognisable blip in the magnetic field, and this is what was also picked up on Europa.

Galileo's Plasma Wave Spectrometer (PWS) measured the plasma waves caused by charged particles in the gas comprising Europa's atmosphere. The results from this alone weren't enough, and Jia and the team followed up these readings with 3D models and simulations of the interactions of plasma with Solar System bodies. Hubble's observations were the missing piece of the puzzle.

NASA/ESA's Hubble Space Telescope revealed the location of water vapour at Europa in 2012

These results provide NASA's Europa Clipper mission with a great challenge ahead of its scheduled launch in June 2022; it will sail close to Jupiter's moon in a series of rapid, low-altitude flybys. "If plumes exist, and we can directly sample what's coming from the interior of Europa, then we can more easily get at whether Europa has the ingredients for life," says Robert Pappalardo, Europa Clipper project scientist at NASA's Jet Propulsion Laboratory (JPL) in California. "That's what the mission is after. That's the big picture."

"If we can sample what's coming from the interior we can get at whether Europa has the ingredients for life"

© NASA/ESA; Tobias Roetsch

STARGAZER

GUIDES AND ADVICE TO GET STARTED IN AMATEUR ASTRONOMY

In this issue...

What's in the sky?

21 JUN
June solstice

23 JUN
Open cluster NGC 6530 is well placed for observation in Sagittarius

23 JUN
Globular cluster NGC 6541 is well placed for observation in Corona Australis

27 JUN
Saturn reaches opposition in Sagittarius, shining at magnitude 0

28 JUN
Open cluster NGC 6633 is well placed for observation in Ophiuchus

1 JUL
Globular cluster Messier 22 is well placed for observation in Sagittarius

1 JUL
Open star cluster IC 4756 is well placed for observation in Serpens

1 JUL
Conjunction between the Moon and Mars in Capricornus

10 JUL
Comet P/2013 CU129 (PANSTARRS) reaches its brightest at magnitude 11.4

12 JUL
Mercury is well placed for observation in the evening sky, shining at magnitude 0.4

12 JUL
Pluto reaches opposition in the constellation of Sagittarius

Jargon buster

Conjunction
A conjunction is an alignment of objects at the same celestial longitude. The conjunction of the Moon and the planets is determined with reference to the Sun. A planet is in conjunction with the Sun when it and Earth are aligned on opposite sides of the Sun.

Right Ascension (RA)
Right Ascension is to the sky what longitude is to the surface of the Earth, corresponding to east and west directions. It is measured in hours, minutes and seconds since, as the Earth rotates on its axis, we see different parts of the sky throughout the night.

Declination (Dec)
This tells you how high an object will rise in the sky. Like Earth's latitude, Dec measures north and south. It's measured in degrees, arcminutes and arcseconds. There are 60 arcseconds in an arcminute and there are 60 arcminutes in a degree.

Magnitude
An object's magnitude tells you how bright it appears from Earth. In astronomy, magnitudes are represented on a numbered scale. The lower the number, the brighter the object. So, a magnitude of -1 is brighter than an object with a magnitude of +2.

Opposition
When a celestial body is in line with the Earth and Sun. During opposition, an object is visible for the whole night, rising at sunset and setting at sunrise. At this point in its orbit, the celestial object is closest to Earth, making it appear bigger and brighter.

Greatest elongation
When the inner planets, Mercury and Venus, are at their maximum distance from the Sun. During greatest elongation, the inner planets can be observed as evening stars at greatest eastern elongations and as morning stars during western elongations.

23 JUN
Conjunction between the Moon and Jupiter in Libra

23 JUN
The Moon and Jupiter make a close approach, passing within 4°01' of each other Libra

24 JUN
Comet P/2013 CU129 (PANSTARRS) makes its closest approach to the Sun in Hydra

28 JUN
Conjunction between the Moon and Saturn in Sagittarius

28 JUN
The Moon and Saturn make a close approach, passing within 1°46' of each other in Sagittarius

1 JUL
The Moon and Mars, pass within 4°41 of each other in Capricornus

6 JUL
Comet 37P/Forbes reaches its brightest, reaching a predicted magnitude of 11.1

7 JUL
Mercury is at dichotomy, reaching half phase in the evening sky

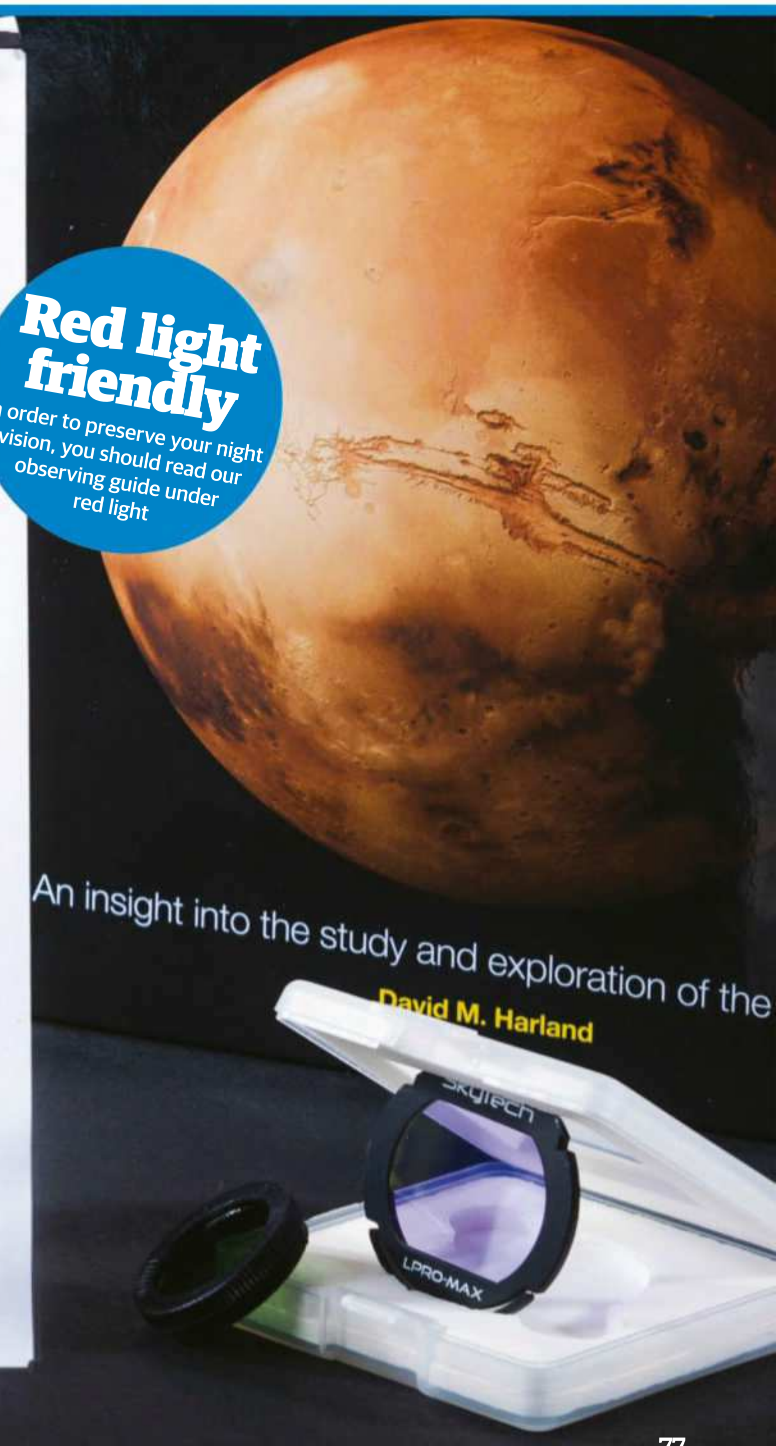
8 JUL
The Capricornids reach their peak of 5 meteors per hour

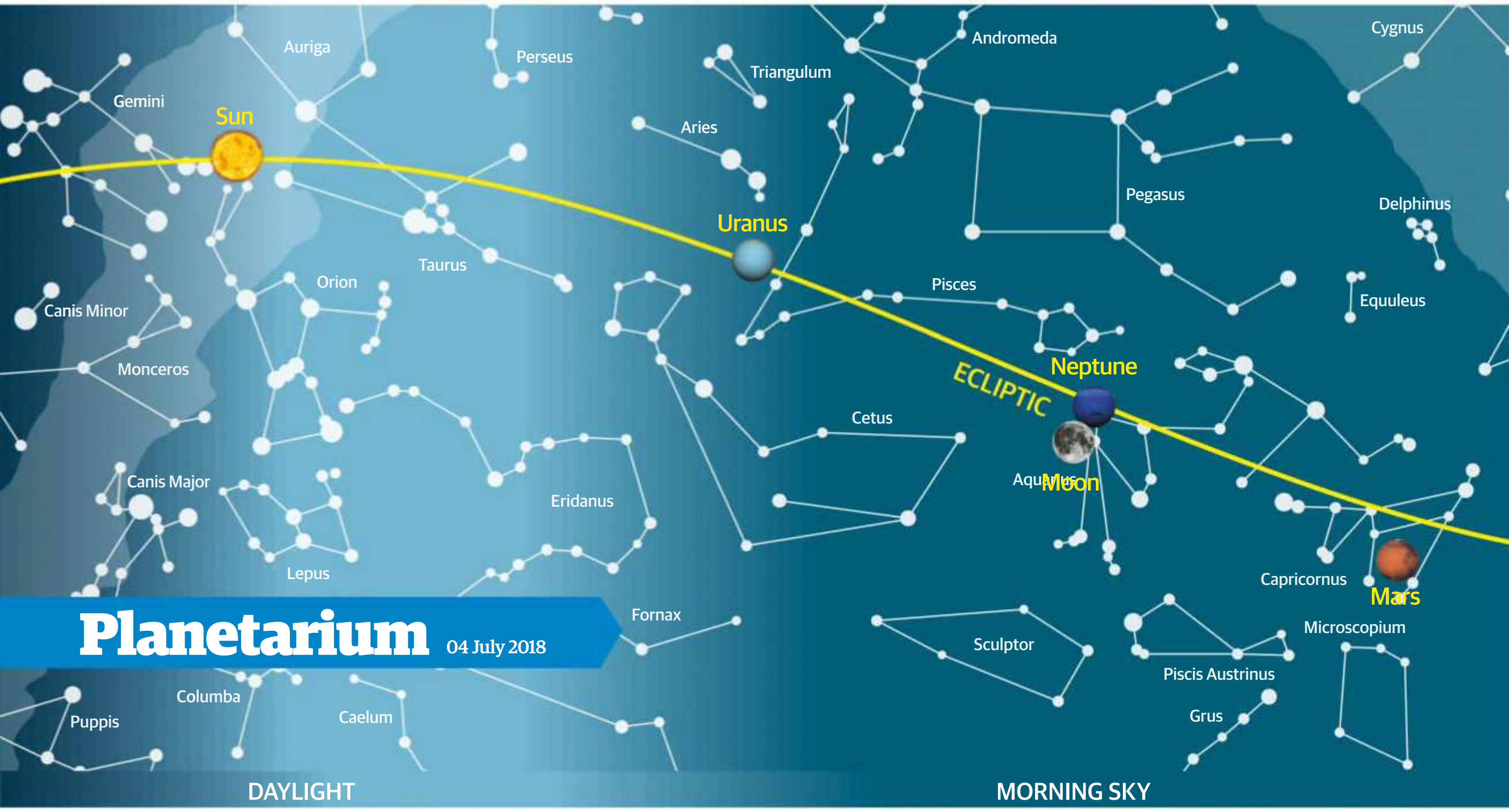
13 JUL
Partial solar eclipse visible from Antarctica, Australia and New Zealand

15 JUL
The Capricornids reach their peak of five meteors per hour

- Naked eye
- Binoculars
- Small telescope
- Medium telescope
- Large telescope

Red light friendly
In order to preserve your night vision, you should read our observing guide under red light





Planetarium

04 July 2018

Moon calendar

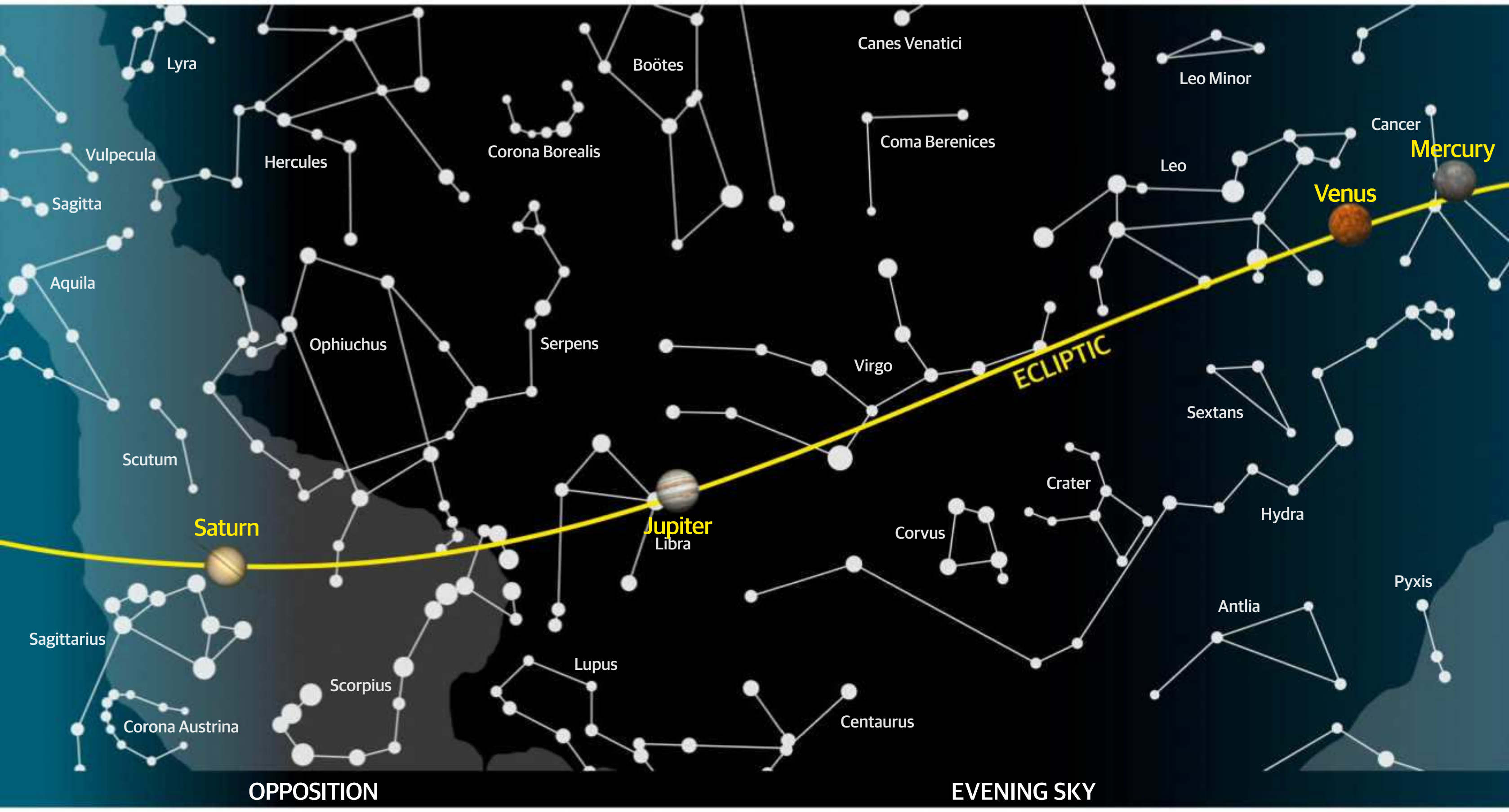
* The Moon does not pass meridian on 26 June

Date	Phase	Illumination	Moonrise	Moonset
21 JUN		64.4%	14:05	01:42
22 JUN		74.3%*	15:16	02:04
23 JUN		82.9%	16:25	02:27
24 JUN		89.9%	17:33	02:51
25 JUN		95.1%	18:39	03:18
26 JUN		*%	19:41	03:48
27 JUN		98.5%	20:37	04:25
28 JUN	FM	99.9%	21:28	05:07
29 JUN		99.4%	22:11	05:56
30 JUN		96.9%	22:47	06:51
1 JUL		92.7%	23:18	07:51
2 JUL		86.8%	23:45	08:53
3 JUL		79.5%	--:--	09:58
4 JUL		70.9%	00:08	11:04
5 JUL		61.3%	00:30	12:11
6 JUL	LQ	50.9%	00:51	13:20
7 JUL		40.2%	01:13	14:32
8 JUL		29.5%	01:37	15:46
9 JUL		19.5%	02:04	17:03
10 JUL		10.9%	02:38	18:20
11 JUL		4.4%	03:20	19:33
12 JUL		0.7%	04:13	20:39
13 JUL	NM	0.3%	05:18	21:33
14 JUL		3.2%	06:34	22:17
15 JUL		9.2%	07:54	22:52
16 JUL		17.5%	09:15	23:21
17 JUL		27.4%	10:35	23:46
18 JUL		38.3%	11:51	--:--
19 JUL	FQ	49.3%	--:--	00:10

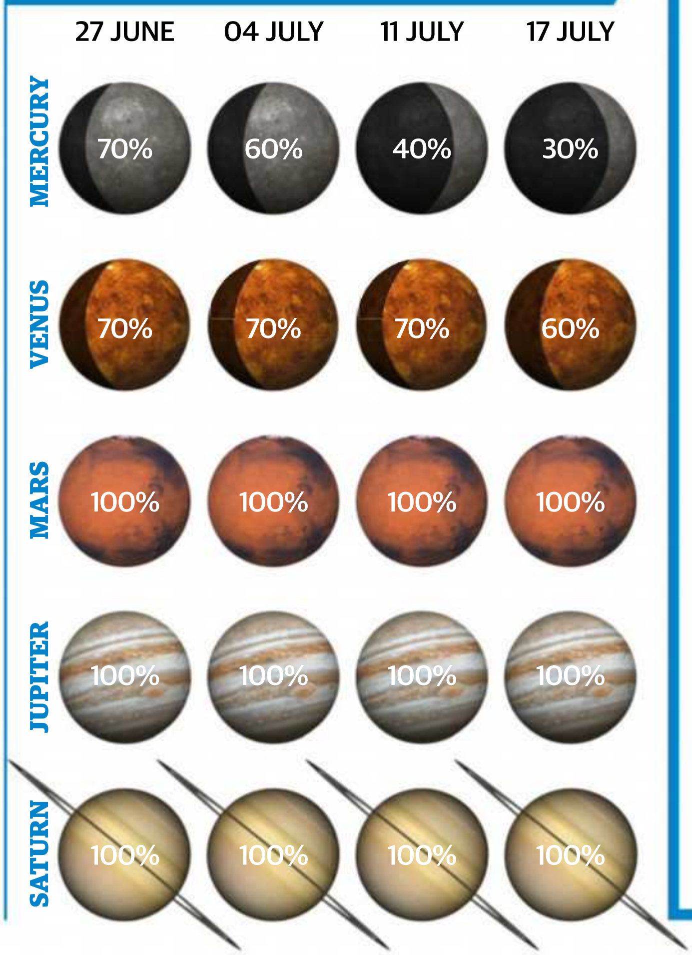
% Illumination
Moonrise time
Moonset time

FM Full Moon
NM New Moon
FQ First quarter
LQ Last quarter

All figures are given for 00h at midnight (local times for London, UK)



Illumination percentage



Planet positions

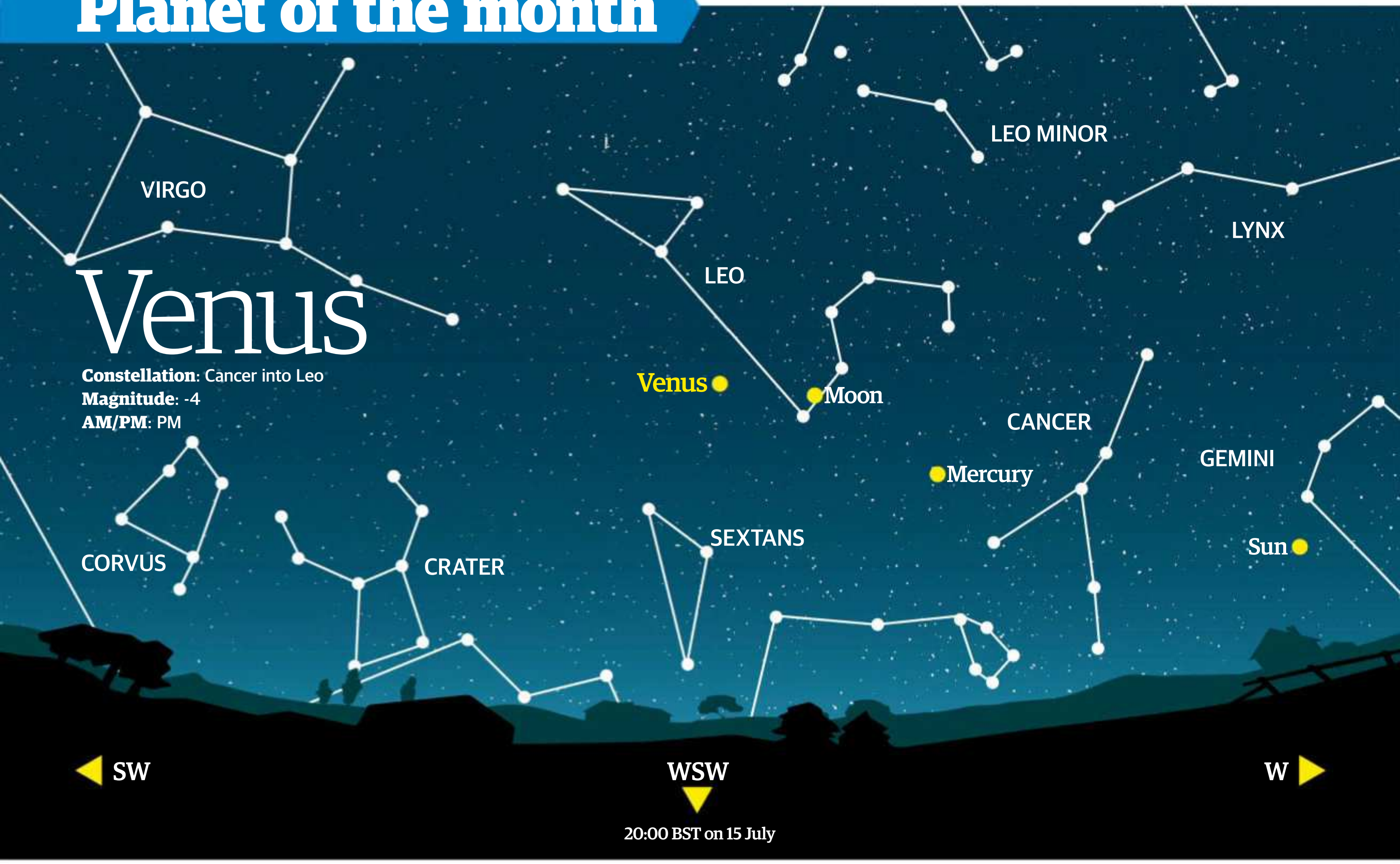
All rise and set times are given in BST

	Date	RA	Dec	Constellation	Mag	Rise	Set
MERCURY	21 June	07h 10m 12s	+24° 27' 01"	Gemini	-0.7	05:47	22:36
	27 June	07h 54m 34s	+22° 35' 54"	Gemini	-0.3	06:21	22:43
	04 July	08h 36m 52s	+19° 34' 58"	Cancer	0.0	06:56	22:37
	11 July	09h 12m 31s	+16° 13' 18"	Cancer	0.3	07:21	22:21
	17 July	09h 27m 27s	+13° 29' 16"	Leo	0.7	07:32	22:00
VENUS	21 June	08h 43m 48s	+20° 10' 57"	Cancer	-4.0	07:50	23:59
	27 June	09h 11m 46s	+18° 09' 59"	Cancer	-4.0	08:07	23:31
	04 July	09h 43m 10s	+15° 29' 26"	Leo	-4.1	08:27	23:19
	11 July	10h 13m 16s	+12° 31' 51"	Leo	-4.1	08:47	23:04
	17 July	10h 38m 05s	+09° 49' 06"	Leo	-4.1	09:02	22:51
MARS	21 June	20h 49m 31s	-22° 10' 29"	Capricornus	-1.8	23:52	08:07
	27 June	20h 50m 56s	-22° 32' 57"	Capricornus	-2.0	23:33	07:43
	04 July	20h 50m 12s	-23° 08' 01"	Capricornus	-2.2	23:08	07:10
	11 July	20h 46m 55s	-23° 50' 38"	Capricornus	-2.5	22:42	06:35
	17 July	20h 42m 14s	-24° 30' 12"	Capricornus	-2.6	22:19	06:02
JUPITER	21 June	14h 46m 16s	-14° 50' 52"	Libra	-2.4	17:07	02:48
	27 June	14h 45m 03s	-14° 46' 58"	Libra	-2.3	16:42	02:24
	04 July	14h 44m 11s	-15°08'16"	Libra	-2.3	16:13	01:55
	11 July	14h 43m 52s	-14° 45' 21"	Libra	-2.3	15:46	01:28
	17 July	14h 44m 04s	-14° 47' 56"	Libra	-2.2	15:22	01:04
SATURN	21 June	18h 26m 18s	-22° 26' 15"	Sagittarius	0.1	21:31	05:43
	27 June	18h 24m 24s	-22° 27" 51'	Sagittarius	0.0	21:06	05:17
	04 July	18h 22m 11s	-22° 29' 43"	Sagittarius	0.1	20:36	04:47
	11 July	18h 20m 00s	-22° 31' 31"	Sagittarius	0.1	20:07	04:17
	17 July	18h 18m 13s	-22° 32' 59"	Sagittarius	0.1	19:42	03:52

This month's planets

Venus takes pride of place in the evening, dazzling in the west, while Mercury, Mars, Jupiter and Saturn also shine

Planet of the month



Venus

Constellation: Cancer into Leo
Magnitude: -4
AM/PM: PM

This is a great month for you if you enjoy the lovely sight of Venus shining brightly in the sky at the end of the day. Through June and July Venus is a bright 'Evening Star', and it can be found in the west as soon as the sky starts to darken after sunset. Shining at magnitude -4 it will be the brightest object in the sky after the Sun and the Moon and will blink into view long before the first stars appear. By the time twilight has deepened enough for the brightest stars to be seen, Venus will be a strikingly bright point of light, drawing the eye away from everything else.

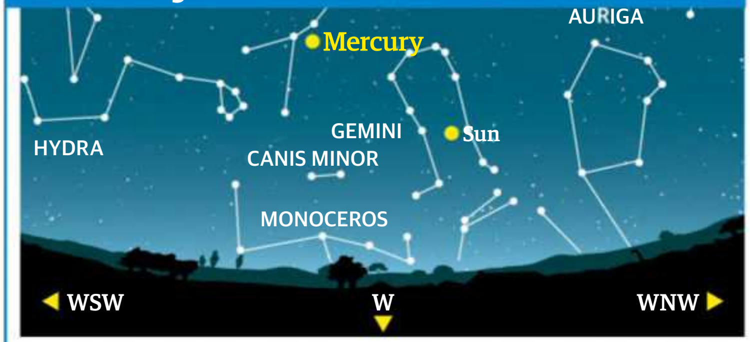
At the start of our observing period Venus will be shining to the upper left of much fainter Mercury, a short distance to the left of the famous star cluster M44, or 'The Beehive Cluster'. You should be able to see the cluster's myriad of stars through binoculars as twilight deepens. By the middle of July Venus will have drifted away from M44 and will have slipped into the constellation of Leo, heading for a close encounter with its brightest star, Regulus. By the time Venus is shining directly above Regulus on the evening of 9 July – less than two Moon width's from the star – it will actually be a little brighter than it was in late June, but will be setting sooner so you'll have less time to enjoy it.

Cross your fingers for a clear sky on the evening of 15 July because we'll be treated to the sight of a very thin crescent Moon shining between Venus to its left and Regulus to its right. The Moon and Venus will be just four degrees apart, and although they will have sunk quite low in the sky by the time the sky is dark enough for the crescent Moon to show the subtle lavender glow of Earthshine, it will still be worth looking out for.

July will be a very good time to take a look at Venus through your telescope, if you have one. The planet will appear large in even a medium-magnification eyepiece, and its disc will be just over half-illuminated, making it appear like the Moon does a couple of days after first quarter.

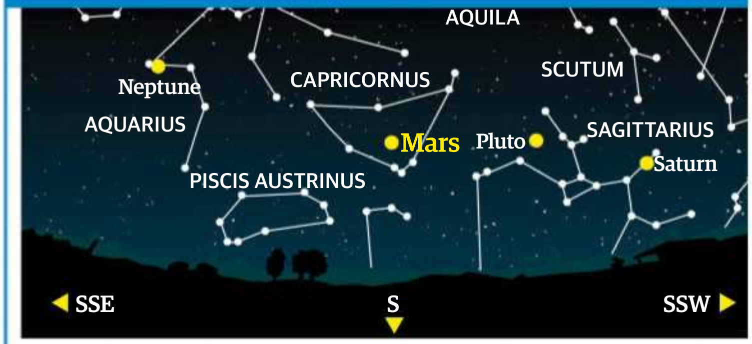
Although its observations and results don't make the news headlines as often as missions to the other planets in our Solar System do, there is actually a Japanese space probe orbiting and studying Venus right now. The Akatsuki, or 'Venus Climate Orbiter', went into orbit around Venus in December 2015 and has collected a wealth of data about the planet. It has also returned many photos which, when processed, have revealed fine details and dramatic structures in the planet's turbulent atmosphere never seen before. You can find them online if you want a closer look.

Mercury 19:00 BST on 3 July



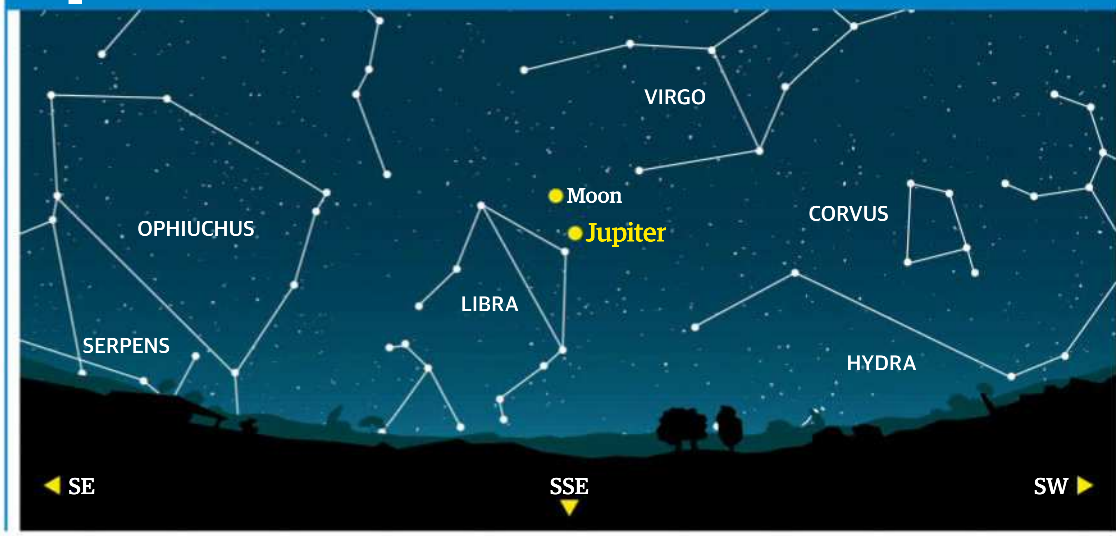
Constellation: Gemini into Cancer
Magnitude: -0.6
AM/PM: PM
At the start of our observing period Mercury is an evening star, low in the northwest after sunset and setting around an hour after. At magnitude 0.6 it is visible to the naked eye, despite its low elevation in the sky. By 9 July Mercury will have started to fade and drop towards the horizon, each evening setting a little earlier.

Mars 03:00 BST on 1 July



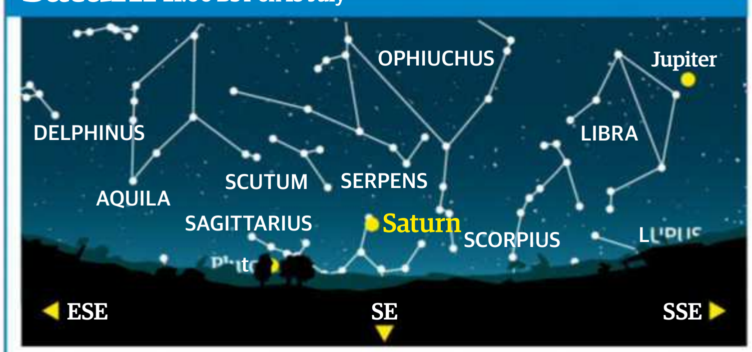
Constellation: Capricornus
Magnitude: -1.7 brightening to -2.6
AM/PM: AM
By the end of June Mars will be rising in the east just after midnight, trailing behind Jupiter and Saturn. By 1 July it will have brightened to magnitude -2.2, and by mid-July will be considerably brighter at magnitude -2.6. The Moon approaches and then passes Mars between 30 June and 2 July.

Jupiter 20:00 BST on 23 June



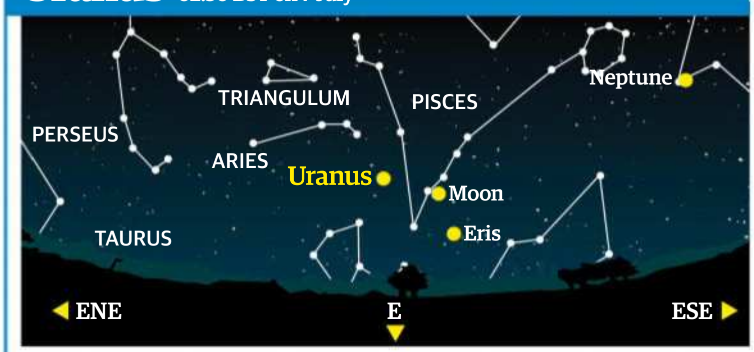
Constellation: Libra
Magnitude: -2.4
AM/PM: PM
On late-June evenings Jupiter will already be fairly high in the south as the sky begins to darken and the stars come out. Shining at magnitude -2.4 it is immediately obvious to the naked eye throughout the warm, short summer nights. The almost-full Moon will drift towards and then past Jupiter between 23 and 25 June, shining directly above and just over three degrees from it after dark on the 24th. Throughout the summer months Jupiter will be on the far-right end of a chain of planets, with quickly brightening Mars far over to its lower left and golden-hued Saturn inbetween.

Saturn 21:00 BST on 15 July

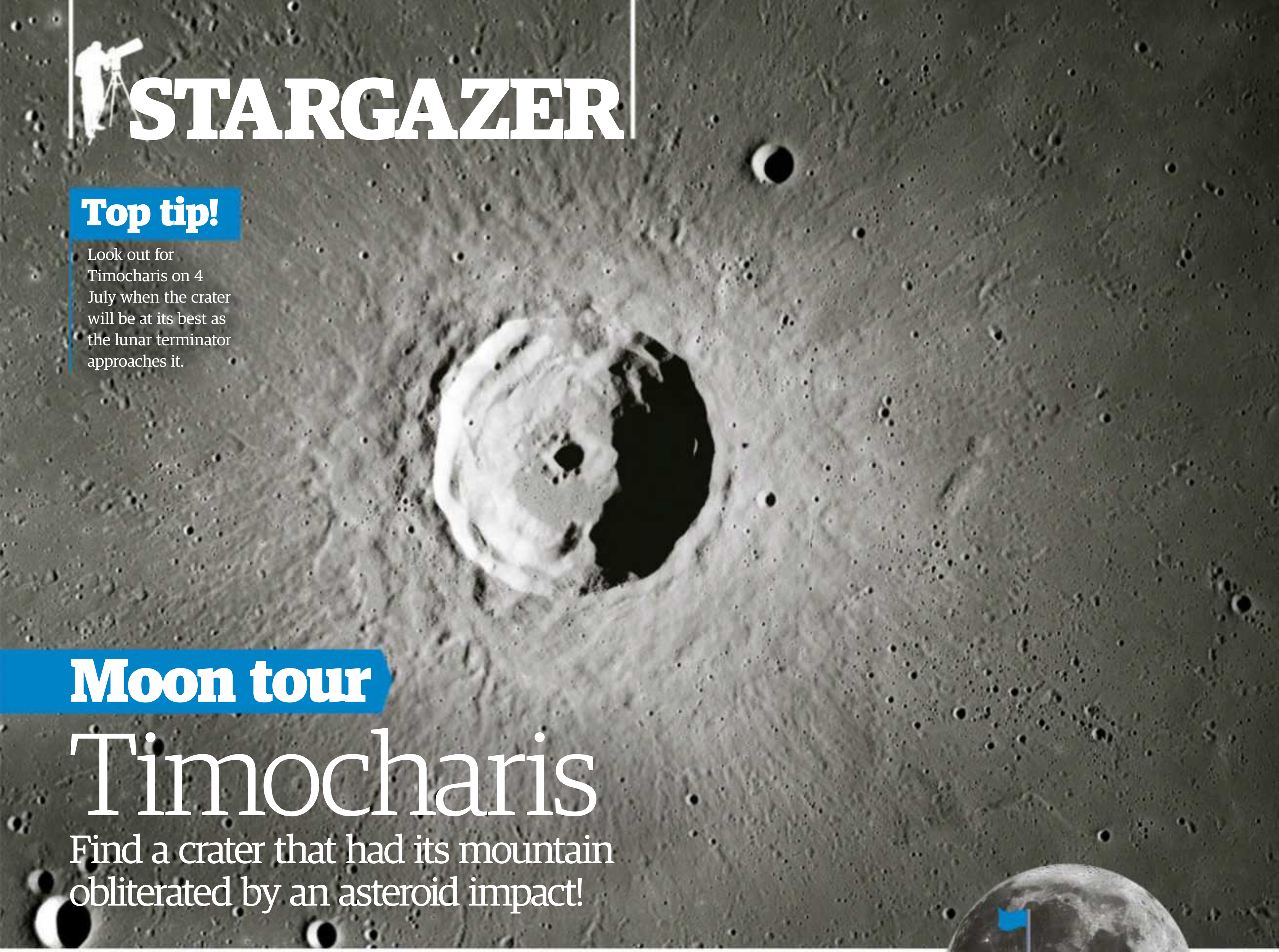


Constellation: Sagittarius
Magnitude: 0.0
AM/PM: PM
Saturn is a golden 'evening star' throughout the summer, visible low in the south as soon as the sky becomes dark enough to see stars. Like Mars it never climbs very high in the sky, and will only appear as a zero magnitude 'star' above and to the left of the famous 'Teapot' asterism of Sagittarius, and to the upper left of ruddy Antares, Scorpius' brightest star.

Uranus 02:30 BST on 7 July



Constellation: Aries
Magnitude: 5.8
AM/PM: AM
Shining at magnitude 5.8, Uranus is technically a naked-eye object. In late June Uranus is rising around 2:30am and is visible for several hours until the brightening of the dawn sky. By the middle of July Uranus rises around midnight, so is visible for longer. Through binoculars it looks like a star with a subtle green tinge.



Top tip!

Look out for Timocharis on 4 July when the crater will be at its best as the lunar terminator approaches it.

Moon tour

Timocharis

Find a crater that had its mountain obliterated by an asteroid impact!

Even a casual glance at the Moon through a telescope, or even a humble pair of binoculars, is enough to tell you that it has been absolutely pummelled and pulverised in its distant past. Everywhere you look on the Moon you will see impact craters, the pits and holes left behind after a piece of space debris – an asteroid, a comet, or just one of the countless billions of chunks of rock that were left circling the Sun after it was born five billion years ago. Some are enormous and are surrounded by dramatic patterns of rays made of rock and dust that sprayed across the landscape when they were formed. Others are much smaller and less imposing, but there are many more of these than there are 'celebrity' craters. And some of these small craters have fascinating stories behind them, and incredible stories to tell.

One such crater is Timocharis, a small crater in Mare Imbrium, the Sea of Showers, the vast dark plain of ancient frozen lava which represents one of the eyes of the 'Man In The Moon'. Timocharis is just 34 kilometres (21 miles) across and 3 kilometres (1.8 miles) deep, so it is dwarfed by its near neighbours, mighty Copernicus to the south west – 96 kilometres (60 miles) wide – and Eratosthenes – 59 kilometres (37 miles) wide – directly to its south, which it forms a tight triangle with.

Timocharis was given its name in 1651 by the lunar observer and cartographer Giovanni Riccioli. He named it in honour of the Greek astronomer and philosopher Timocharis, who working from the famous Library of Alexandria measured lunar star occultations very accurately and also observed Venus occulting a star.

Timocharis is a relatively young crater in lunar terms. We know this because it is not surrounded by any major rays or splashes of debris. When the Moon is full you can see some subtle rays spreading away from the crater, but pale imitations of those which splosh away from its aforementioned neighbours.

Through a telescope at high power Timocharis is revealed to be a much more complicated feature than it first appears. The crater is roughly polygonal in shape, with sharply defined outer walls – a classic lunar crater in that sense – but the inner slopes of its walls are broken up into multiple terraces and ledges, all of which appear to have slumped down towards the floor. This means that when sunlight strikes Timocharis from a steep angle it can look like a target or bullseye on the lunar surface.

Look closely through your telescope eyepiece and you will see that Timocharis has a central mountain peak – or rather, it used to. Where once stood a towering mountain there is now a small, deep crater; some time after Timocharis was formed, an asteroid came hurtling in from deep space, and like Robin Hood splitting a competitor's arrow, it slammed into the mountain at its centre, obliterating it and leaving behind a single crater which now stares out of the heart of Timocharis like an empty eye socket.

So, when can you see this fascinating but little-known crater?

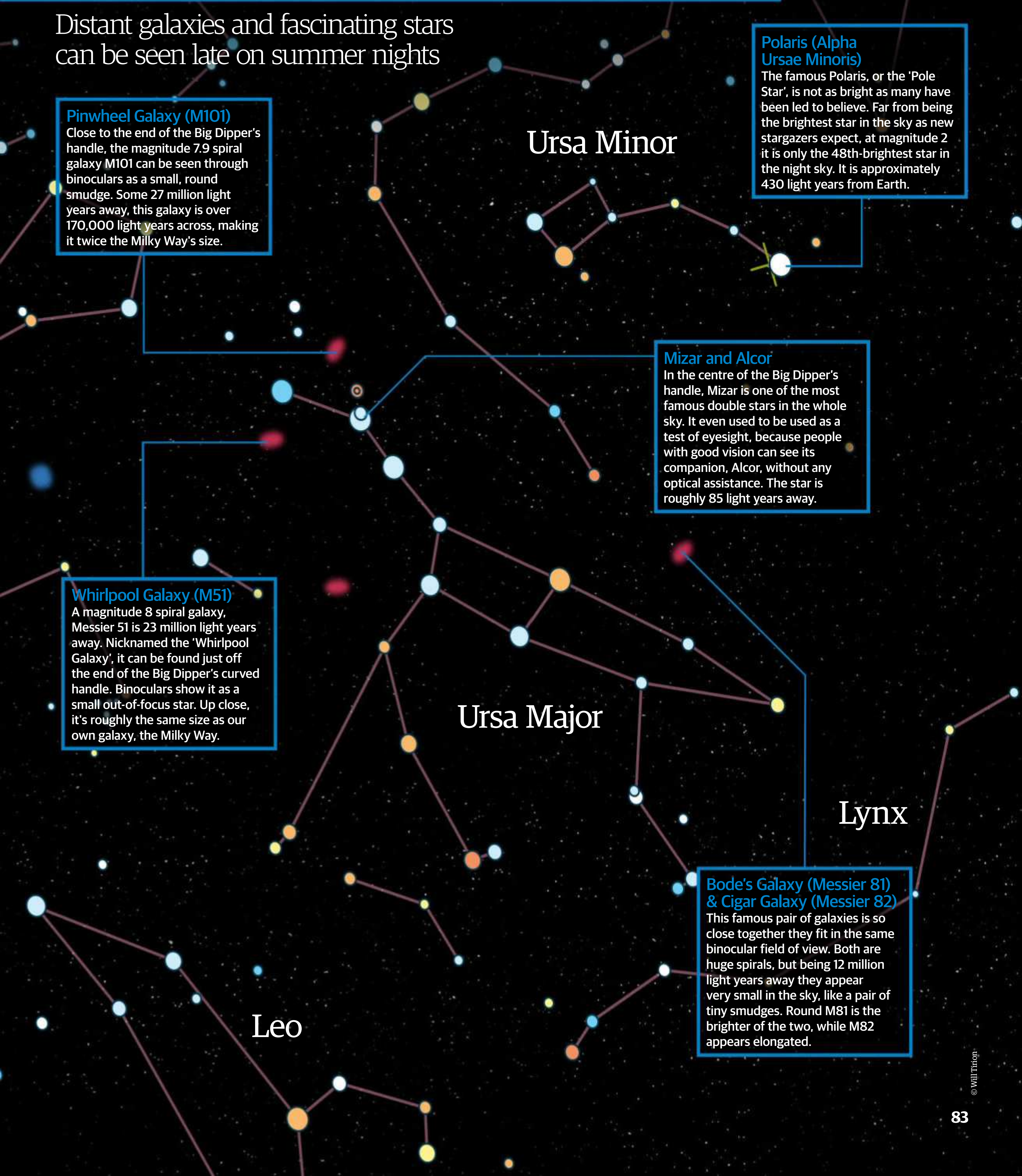
At the start of our observing period Timocharis is very hard to see, as the terminator – the line between lunar night and day – will be almost on top of it. By 22 June the crater will have emerged into the sunlight, and for the next few evenings will be easy to spot, looking like a small, round pit or hole above larger Eratosthenes. When the Moon reaches full on 28 June Timocharis will have blended into the background and will look just like a dark spot with a slightly lighter circular rim.

Timocharis will start to appear more prominent on 4 July, when the terminator will begin to approach it. On 6 July the terminator will sweep over the crater, plunging it into darkness, and we will lose sight of it.

Little Timocharis might not be the most impressive crater on the Moon, but it's a reminder that every feature on the surface of Earth's satellite is worth looking at, and has its own story to tell. All we need to do is listen.

This month's naked eye targets

Distant galaxies and fascinating stars can be seen late on summer nights



Pinwheel Galaxy (M101)
Close to the end of the Big Dipper's handle, the magnitude 7.9 spiral galaxy M101 can be seen through binoculars as a small, round smudge. Some 27 million light years away, this galaxy is over 170,000 light years across, making it twice the Milky Way's size.

Polaris (Alpha Ursae Minoris)
The famous Polaris, or the 'Pole Star', is not as bright as many have been led to believe. Far from being the brightest star in the sky as new stargazers expect, at magnitude 2 it is only the 48th-brightest star in the night sky. It is approximately 430 light years from Earth.

Mizar and Alcor
In the centre of the Big Dipper's handle, Mizar is one of the most famous double stars in the whole sky. It even used to be used as a test of eyesight, because people with good vision can see its companion, Alcor, without any optical assistance. The star is roughly 85 light years away.

Whirlpool Galaxy (M51)
A magnitude 8 spiral galaxy, Messier 51 is 23 million light years away. Nicknamed the 'Whirlpool Galaxy', it can be found just off the end of the Big Dipper's curved handle. Binoculars show it as a small out-of-focus star. Up close, it's roughly the same size as our own galaxy, the Milky Way.

Bode's Galaxy (Messier 81) & Cigar Galaxy (Messier 82)
This famous pair of galaxies is so close together they fit in the same binocular field of view. Both are huge spirals, but being 12 million light years away they appear very small in the sky, like a pair of tiny smudges. Round M81 is the brighter of the two, while M82 appears elongated.

How to...

Get children started in observing the night sky

A young audience will be awed by the beauty of the stars and planets, but how do you keep their enthusiasm going? Here are a few pointers...

You'll need:

- ✔ Planisphere
- ✔ Binoculars
- ✔ Small telescope

Youngsters have a great natural wonder for the night sky and all that's in it. Show a child of almost any age the Moon through a telescope for the first time and you will be greeted by gasps and exclamations. Keeping up this enthusiasm can be more challenging though, and if you don't know a lot about the night sky yourself it can seem a bit daunting. However, you can make it interesting for both yourself and the child or children with good preparation.

Of course, it depends on the age of the child to what level you need to pitch your information. A five year old will probably be quite happy just looking at the Moon, or hearing about some of the stories of the constellations, but an older child will possibly want more details and facts and figures. It is worth investing in a planisphere if you don't already have one, as this will help you to know which constellations are visible in the night sky at any given time of year, along with where you can expect to find them. There are a plethora of books available which should pique a youngster's interest and remind many adults of what's 'out there'.

There are websites and software which can prove invaluable for helping beginners of all ages get to grips with the heavens. Stellarium, for example, is a complete desktop planetarium, and it's free! It will give you representations of the night sky from anywhere on planet Earth and for almost any date. You can delve into it at virtually any level and it can help you plan an observing session, which is a really good idea to keep young minds interested.

Try to keep it suitable for the age group concerned and avoid the temptation to give too much information. If you have a telescope, make sure you are comfortable with operating it and understand what can be seen through it. Keeping children waiting while you try to find that faint fuzzy object can be disastrous, so stick to bright, easy-to-find objects at first. Look to joining a local astronomical society, as many of them have youth sections. Above all, have fun, as this is what will keep children coming back time after time.

> "An older child will possibly want more details and facts and figures"

Tips & tricks

Use a planisphere

A planisphere will enable you to show children constellations and where they are. Get them to practice during the day before observing.

Learn to use binoculars

Show children how to use binoculars. They're the easiest observing equipment to use, so ensure they are sufficiently lightweight.

Wrap up warm

This is important as youngsters can feel the cold quite easily at night, and being too cold will divert their interest.

Introduce a telescope

Familiarise yourself with the workings of your telescope and show the child how to use it properly and safely.

Books and software

There are books for all ages to stimulate interest along with dozens of websites that do the same.

A youngster's guide to astronomy

Don't overlook what can be seen with just the naked eye...

Binoculars and telescopes are a great aid for exciting children about the night sky. It's worth showing them how to use these instruments properly so that they get the best out of them and use them safely. Warnings about pointing optical equipment at the Sun should always be done early on. It is also worth pointing out all the things that can be seen without optical help.

Send your photos to **space@spaceanswers.com**

1 Look to the lunar surface

The Moon is a great object to start with. While they're gazing upon its craters and lunar mare with binoculars or the naked eye, talk about its phases and how it orbits around us.

2 Learn the constellations

Point out some of the more familiar shapes, like Orion or the Great Bear, and point out where they are on your sky map or planisphere. Tie in a bit of mythology to make learning fun!

3 Talk about the seasons

It's worth explaining about how the sky changes with the seasons as we orbit the Sun. You can use the planisphere to show the young audience what constellations they'll be able to see.

4 Introduce optics

Show your child how to focus the binoculars or telescope. The more they play around with the optical system during their observations, the more they'll understand how to use it.

5 Seek out the planets

Show the bright planets to the child through a telescope if possible, with explanations suitable for their age. The planets are the easiest and most awe-inspiring objects in the night sky.

6 Encourage questions

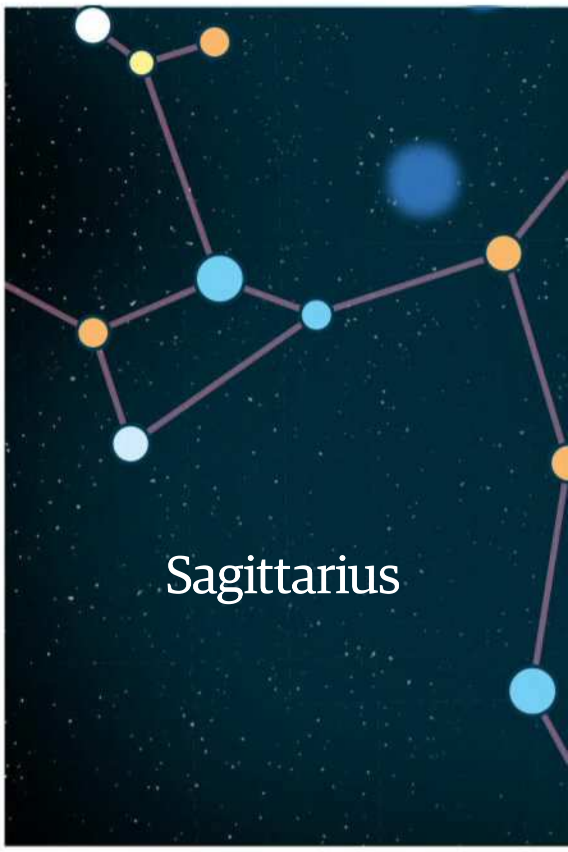
Encourage your audience to ask questions and look things up in books or on the Internet. The more they learn about the universe, the more they'll be inspired to keep looking up.

Lagoon Nebula (Messier 8)

Deep sky challenge

Tour the treasures of Sagittarius and Scorpius

Prepared to stay up until the early hours? Then the night sky is stuffed with an impressive array of objects



Summer in mid-northern latitudes gives us short nights that are never truly dark, wreaking havoc on your viewing plans. However, the skies are dark enough to see some real celestial wonders. This month, the Milky Way arcs almost from north to south, bringing with it all kinds of deep-sky gems, including open star clusters, globular star clusters and nebulae on which to feast your eyes. Down near the southern horizon you will find the constellations of Scorpius and Sagittarius, which are packed with many such objects. For example, there is open star cluster Messier 7 – this object can be challenging for Northern Hemisphere observers as it is so close to the horizon during this time of the year. On the other hand, the exquisite Eagle Nebula, also known as Messier 16, is more straight-forward to spot. Take a tour of just a few of the glorious objects within the borders of the Archer and the Scorpion for almost any size of telescope - there are plenty of mesmerising sights.

1 Ptolemy Cluster (Messier 7)

This open cluster is a treat through a telescope. Sitting close to the 'stinger' of the scorpion, it is considered a challenging object for observers in northern latitudes since Scorpius never rises very high above the horizon. Look 4.75 degrees northeast of the star Lambda Scorpii, the second brightest star in the constellation, to locate this open cluster.

2 Butterfly Cluster (Messier 6)

Known as the Butterfly Cluster, this is another great cluster for a small telescope. The majority of the stars within this open cluster are hot, young, blue stars. A moderately sized telescope will enable views of the stellar gathering's orange giant, which ranges in brightness from magnitude 5.5 through to magnitude 7.

3 NGC 6553

This is a very loose globular star cluster in Sagittarius. NGC 6553 can be found quite easily after locating the Lagoon Nebula, where it sits just over a degree southeast of it. Packed with stars of magnitude 20 or dimmer, you will require a telescope with a large aperture in order to observe it effectively.

4 Lagoon Nebula (Messier 8)

A small telescope at low power will reveal a faint oval patch of light with a definite core. The nebula is currently undergoing a period of active star formation. The group covers roughly 14 arcminutes in the sky and glows at a magnitude of about 6. You should look to the southern horizon and just above and to the right of Sagittarius' Teapot asterism.

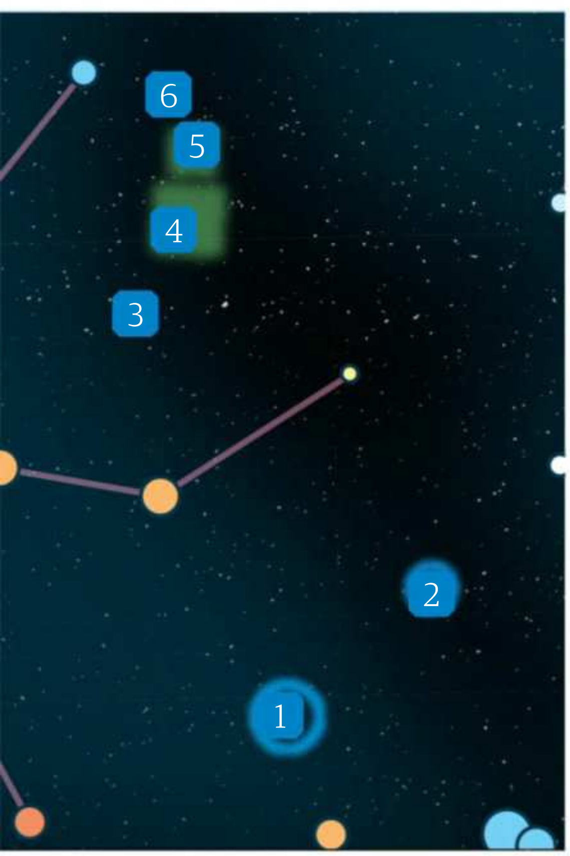
5 Trifid Nebula (Messier 20)

Just half a degree north of the Lagoon Nebula you will be able to locate the Trifid Nebula, which gets its name thanks to its three-lobed look. Messier 20 consists of different objects - an emission nebula, a dark nebula and a reflection and an open cluster. The nebula is quite bright with a magnitude of 9.0, making it a good target for small telescopes.

6 Messier 21

Tightly packed, this open cluster is best seen at medium power through a larger aperture telescope. Messier 21 consists mainly of small, faint stars, but it's also home to a few blue giants, giving it a densely packed appearance. 35 of the stars within the cluster have visual magnitudes between 8 and 12.

"The Milky Way arcs almost from north to south at this time and brings with it all kinds of deep-sky gems on which to feast your eyes"



NGC 6553

Trifid Nebula (Messier 20)

The Northern Hemisphere

July brings with it a selection of targets, whatever observing kit you have in your arsenal

The constellations of Lyra, Aquila, Hercules, Sagittarius, Scorpius and Ophiuchus are within easy reach this month, packed with night-sky objects.

Fans of the tight-knit globular star clusters should turn their attention to the constellations of Ophiuchus and Hercules, where they will be rewarded with sights of the extremely stellar-rich Messier 10, Messier 12, Messier 14, Messier 13 and Messier 92. Astrophotographers will get great enjoyment from the binary star system Rho Ophiuchi in Ophiuchus, which is surrounded with a red emission nebula and very impressive light- and dark-brown dust lanes. Cygnus is another goldmine, with the Veil Nebula, Fireworks Galaxy and the Crescent Nebula being excellent choices for observation.

Using the sky chart

This chart is for use at 10pm (BST) mid-month and is set for 52° latitude.

01 Hold the chart above your head with the bottom of the page in front of you.

02 Face south and notice that north on the chart is behind you.

03 The constellations on the chart should now match what you see in the sky.

Magnitudes

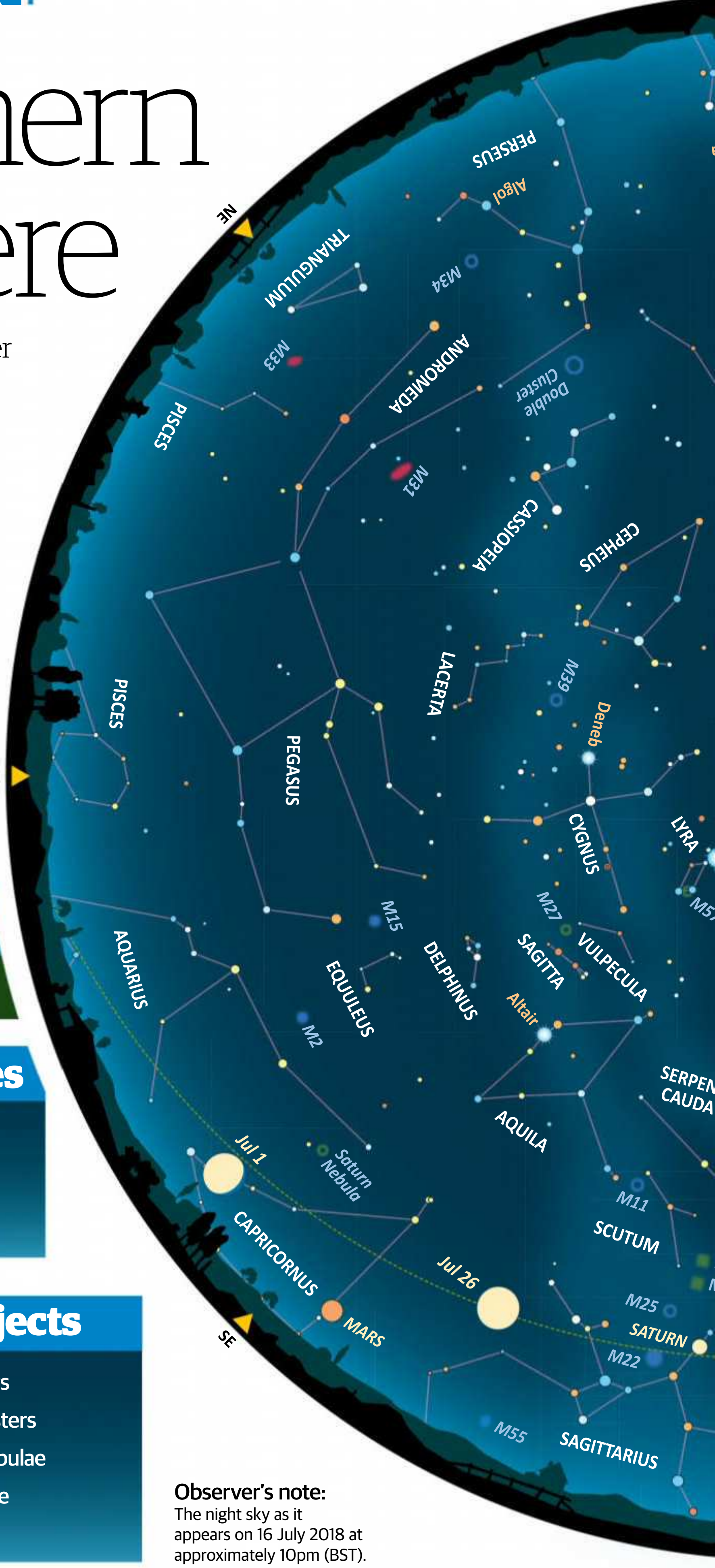
- Sirius (-1.4)
- -0.5 to 0.0
- 0.0 to 0.5
- 0.5 to 1.0
- 1.0 to 1.5
- 1.5 to 2.0
- 2.0 to 2.5
- 2.5 to 3.0
- 3.0 to 3.5
- 3.5 to 4.0
- 4.0 to 4.5
- Fainter
- Variable star

Spectral types

- O-B
- A
- F
- G
- K
- M

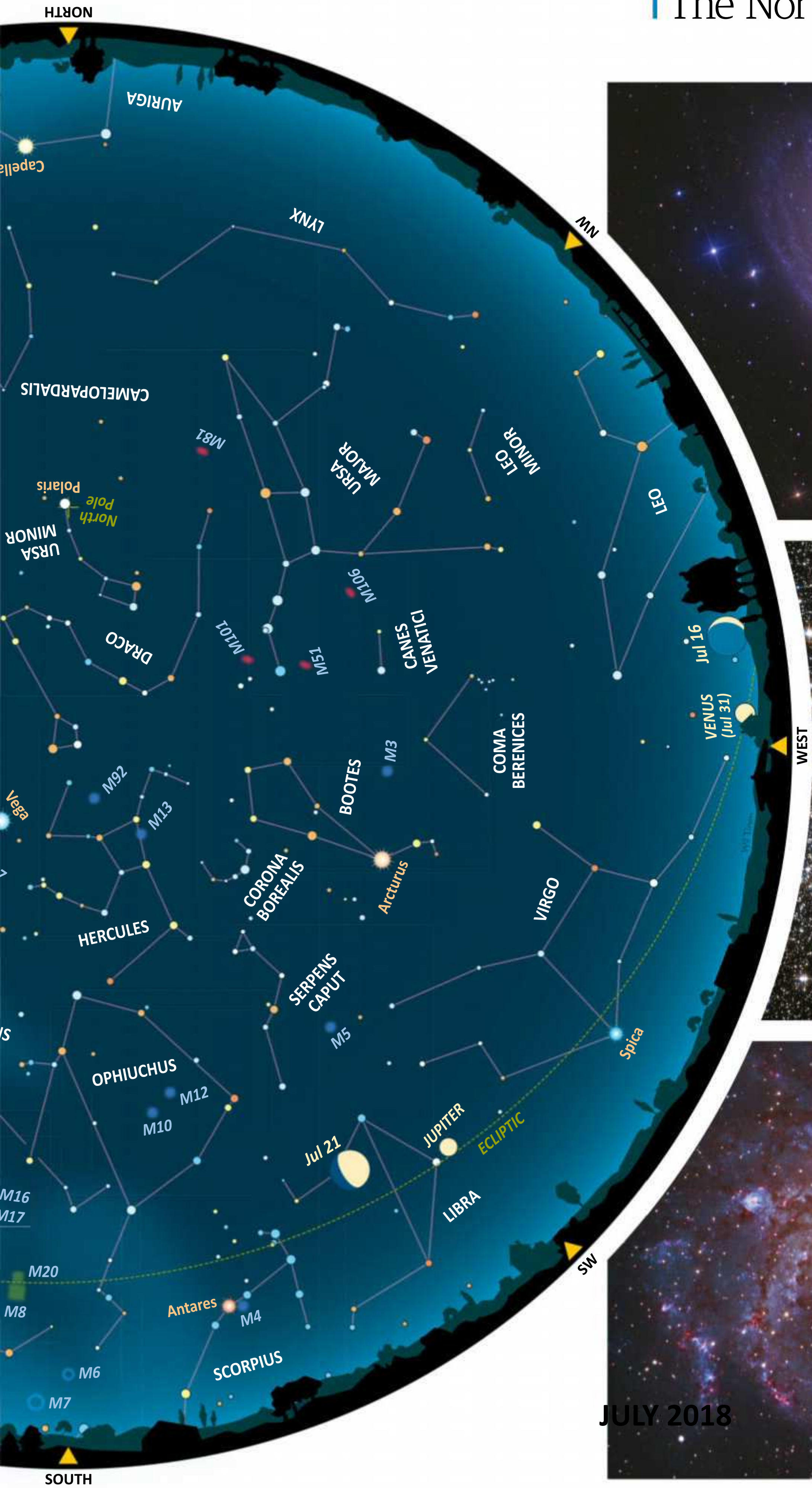
Deep-sky objects

- Open star clusters
- Globular star clusters
- Bright diffuse nebulae
- Planetary nebulae
- Galaxies

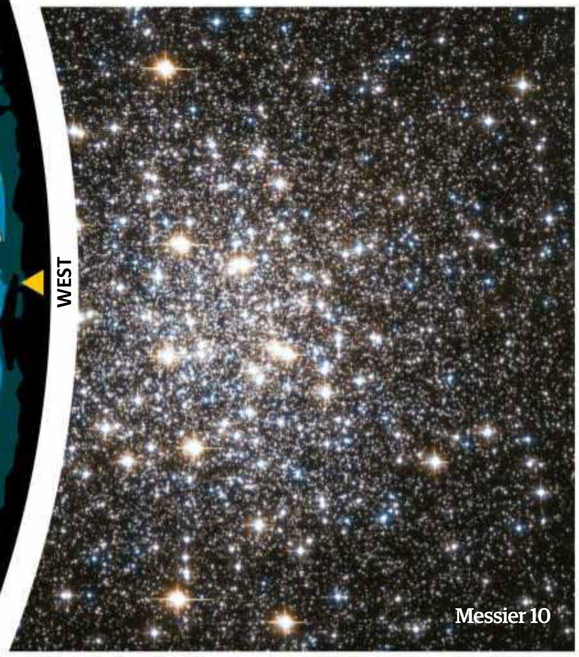


Observer's note:
The night sky as it appears on 16 July 2018 at approximately 10pm (BST).

The Northern Hemisphere



Bode's Galaxy (Messier 81)

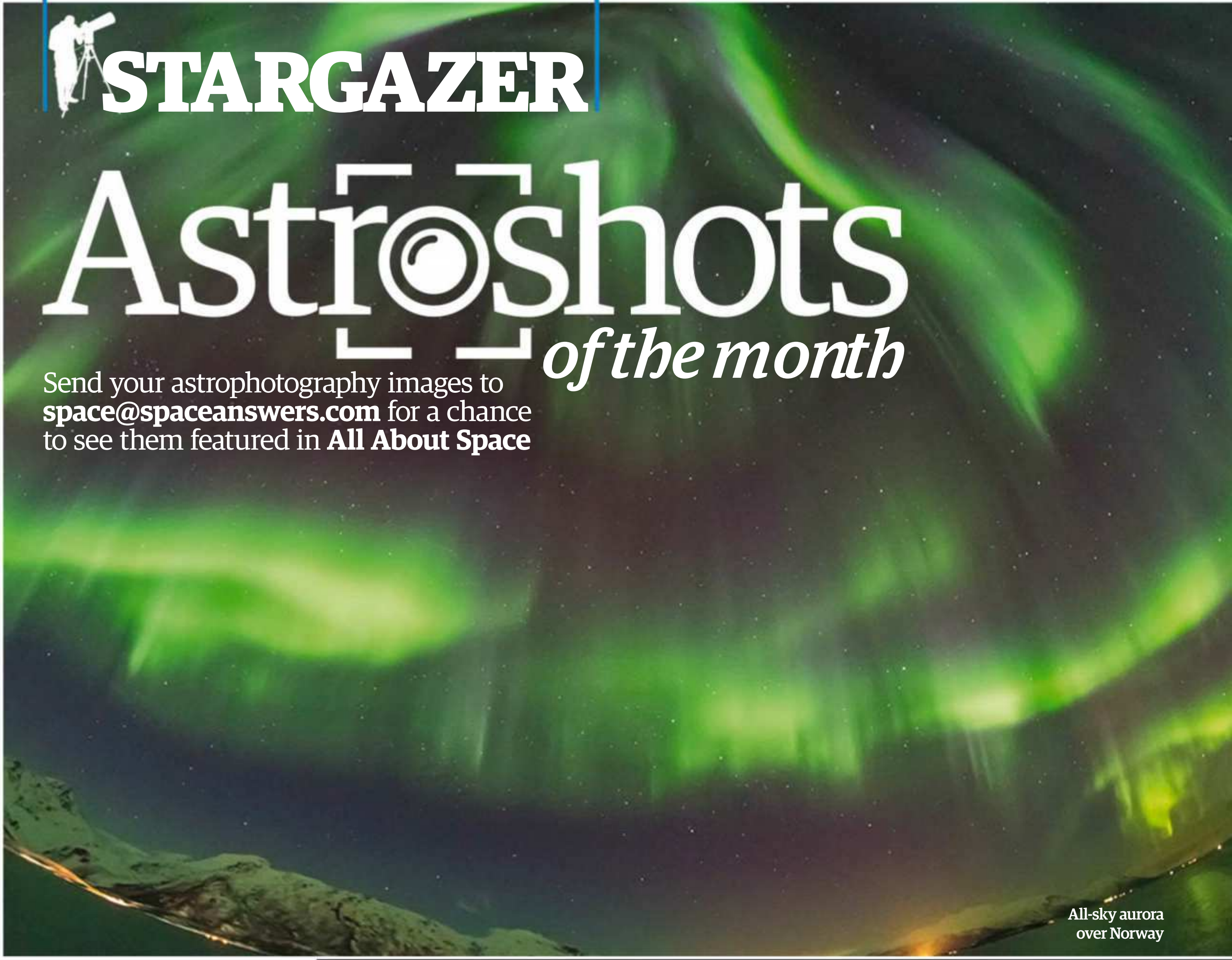


Messier 10

Fireworks Galaxy (NGC 6946)

Astroshots of the month

Send your astrophotography images to **space@spaceanswers.com** for a chance to see them featured in **All About Space**



All-sky aurora over Norway

Alan Dyer

Alberta, Canada
Borg 77mm f/4 Astrograph

"While my home in rural Alberta in western Canada presents fine opportunities for photographing the night sky, I love heading south as often as I can to sites below the equator to take in the wonders of the Southern Hemisphere. Only from 'down under' can you get the best views of the Magellanic Clouds and southern Milky Way sights such as the Carina Nebula.

"To capture the southern spectacles, in April 2016 I spent two weeks under mostly clear nights near Coonabarabran, New South Wales, billed as the 'astronomy capital' of Australia. Most nights were perfect – clear, dry and mild, with no wind, bugs or dew. It was heaven on Earth for stargazing; the finest skies you'll find anywhere."

Time sequence of the 2017 solar eclipse

Roger Hutchinson

London, UK
Celestron Edge HD11

"I first became interested in astronomy and space as a child growing up in the 1970s, right at the end of the Apollo program. My dad helped me build an 8-inch Dobsonian telescope, and through it I caught my first sight of Saturn and the craters and mountains of the Moon. I think I was hooked from that point!

"I started imaging with an old film SLR but the results were never what I had hoped for, so I parked my ambition until digital photography came along and, for the past five or six years, I've been pursuing astrophotography over observational astronomy. Some things never change and my favourite targets are still the planets and the lunar surface."

Matt Dieterich

Montana, USA

The Milky Way with incredible airglow over Glacier National Park made for one incredibly memorable night of shooting a few summers ago. Being out under the stars is a relaxing experience that we as humans can all relate to. You can take similar photos to help protect our night sky with nothing more than a camera, lens and tripod. National Parks are incredible resources, especially for stargazing. Parks conserve the night sky just as they protect the forests, meadows and wildlife."

Send your photos to... @spaceanswers @ space@spaceanswers.com

Meade Adventure Scope 80mm refractor

Suitable for terrestial and astronomical views, this grab-and-go instrument is ideal for the casual astronomer

Telescope advice

Cost: £99.00 (approx $130.00)
From: Hama (UK) Ltd
Type: Refractor
Aperture: 3"
Focal length: 15.75"

Best for...

- Beginners
- Low budget
- Planetary viewing
- Lunar viewing
- Bright deep-sky objects
- Terrestrial viewing

This small achromatic refractor telescope is a compact, lightweight telescope and even comes with its own backpack to solidify its status as a prime portable telescope package. Not just capable of night-time observations, it makes for a fine spotting scope as well, which is ideal given its grab-and-go simplicity.

Our experience with the Adventure Scope was surprising, as it has its distinct pros and equally distinct cons, but overall it is a good telescope for its price. The telescope tube is the standout piece of the package, however, the rest of the equipment lets the bundle down, which I think is fairly reflected in the price. The optics of the telescope capture a fine selection of basic night-sky targets such as the Moon, star clusters and the brighter, 'naked-eye' planets.

When the package arrived, the Adventure Scope and its accessories came already stored in its backpack. Unravelling the bubble wrap within unveiled a cream, metal telescope tube, a metal tripod with retractable legs and its attached alt-azimuth mount. The structure of this telescope seemed fairly sturdy and solid, which should keep it stable. A common problem with a lightweight structure is that wind, or even a light jog, can wobble the telescope and interfere with a good view, especially when you're dealing with views of far-off objects. In a separate bubble-wrapped bag we found the red dot finder, a 1.25" 90-degree diagonal and two Huygens six-millimetre and 18-millimetre eyepieces. At first glance the two eyepieces, which provide magnifications of 22x and 66x, are of poor quality, and so we would recommend using a better pair of eyepieces if you have any spare. Given that the eyepiece holder is 1.25", which is the universal size for eyepieces, it shouldn't cause a problem to replace them, or buy some to use with it.

The red dot finder is suitable for locating fainter objects

When setting up the telescope, we quickly came to realise that the tripod and mount aren't as sturdy as once thought. When moving the mount we found it hard to make slight movements of the telescope to keep up with the continual movement of deep-sky objects, while maintaining a relatively tight lock on the mount without it twisting some of the tripod was difficult as well, thus disrupting our navigation. This tells us that the tripod isn't sturdy enough and doesn't allow for long-duration astronomy observations, and we would therefore recommend purchasing a new mount.

It's the optics that make the telescope though, as this is what brings the distant glimmers into focus before your very eyes. For this bundle Meade has created an achromatic refractor telescope with an aperture of 80 millimetres (three inches) and a focal length of 400 millimetres (15.75 inches). This creates a focal ratio of f/5, which is ideal for striking a nice balance between a good light-gathering capability and good focusing for crisp views. With its coated optics this telescope returns some great views whether you are watching nature or watching the night sky.

The red dot finder is a good addition to the bundle, especially as telescopes that promote 'casual' astronomy can provide flimsy optical finders that struggle to pick out fainter targets. Navigation is a task that can prove difficult to begin with, but improves with practice - even to the point you may not need it to assist with hopping from one target to the next.

May offered a cauldron of great sights for us to test out the optics of the Adventure Scope. Unfortunately the rare conjunction between the Moon and Venus just slipped our grasp, as by the

The bundle comes with two Huygens eyepieces: 6mm and 18mm

time the Sun went down, these two sights were too low in the sky. Instead, we had to settle for some equally inspiring sights. Lurking high enough in the sky was Jupiter, shining with a magnitude of -2.5. We used the 18mm eyepiece and the red dot finder to locate Jupiter and focus on it, and then we put in the 6mm. We knew that we were definitely looking at Jupiter and could see a few specks of light surrounding it, also known as the Galilean moons.

Looking higher up in the sky, we observed the double star Mizar and Alcor in the constellation Ursa Major. This made for a great sight with both eyepieces, and the telescope did a good job of focusing the light with little aberration, which is impressive with two bright sources so close together. A few days after, we utilised its grab-and-go nature to take it out quickly and look at the Moon. As it was a waxing crescent with minimal illumination, we couldn't see a great deal of the lunar surface, but with the 6mm we were able to deduce a few craters and enjoyed the clarity of the surface at the terminator. Throughout these observations we were very impressed with optics of the telescope given its small and lightweight structure. However, we were less impressed with the tripod, mount and eyepieces.

If you are someone that appreciates or requires an extremely lightweight – with it collectively only weighing 2.4 kilograms, or five pounds – telescope compact enough that you can carry everything, including the accessories, around in its own backpack, then we recommend this product. However, the accessories, mount and tripod could do with an upgrade to improve your astronomical observing sessions.

A spirit level fitted into the mount for

Everything comes already stored in its backpack

WIN!

A CELESTRON 114 LCM COMPUTERISED TELESCOPE

Tour the night sky with ease using this Newtonian with GoTo technology

WORTH £349

Courtesy of David Hinds Ltd, the United Kingdom's Celestron supplier, we are delighted to offer you the chance to win a fantastic computerised telescope - the Celestron 114 LCM, which is perfect for picking out some of the very best sights in the night sky. Whether it's the Moon in its last quarter, or Jupiter and Saturn in the sky at the same time, the 114 LCM provides exquisite sights with stunning contrast and clarity.

Included with the telescope tube and tripod is a red dot finder (attached to the tube), a low- and high-power eyepiece, an accessory tray and a copy of Celestron's own astronomy software, The SkyX. Meanwhile, the Celestron LCM's hand control has a vast database containing 4,033 targets for you to get started in your exploration of the wonders of the night sky.

To be in with a chance of winning, all you have to do is answer this question: Who said this quote?

"When a man sits with a pretty girl for an hour, it seems like a minute. But let him sit on a hot stove for a minute, and it's longer than any hour. That's relativity."

A: Carl Sagan B: Stephen Hawking
C: Albert Einstein

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Visit the website for full terms and conditions at **www.spaceanswers.com/competitions**

CELESTRON
DavidHinds

Congratulations to Geoff Eardley, who is the winner of the Altair GPCAM2 290M Mono Camera

In the shops

The latest books, apps, software, tech and accessories for space and astronomy fans alike

Book Haynes Mars Owners' Workshop Manual

Cost: £22.99 (approx. $30.70) **From:** Haynes Publishing Ltd

The latest instalment in the Haynes' series of space manuals is a comprehensive, well-explained and extremely enlightening book on everything you need to know about Mars. In light of NASA's revolutionary lander InSight - scheduled to arrive at the Red Planet in November 2018 - author Dr David M Harland has revealed the inside story of the planet, from its birth to today, and the spacecraft that has explored its surface.

Since its discovery in the early 17th Century, Mars has been the subject of many studies. It has had an array of satellites, rovers and landers sent there in the last two decades. Each of these missions and what we have learned from them, among other studies, have been explained in great detail in this book.

A favourable chapter in this book is titled 'Mars in fiction', which steers away from the preconception that Haynes is jam-packed with facts and figures. The appealing nature of this chapter is that it looks at how the idea of indigenous life on Mars and its closeness - relative to the other planets - has led to some fantastic science fiction. Ideal for all space fanatics, Haynes Mars Owners' Workshop Manual gets a thumbs up from us!

App Observer Pro: Astronomy Planner

Cost: £13.99 / $13.99 **For:** iOS

Ideal for optimising your observing session, *Observer Pro* has been created to provide a comprehensive list of deep-sky objects, with information tailored to help astronomers know when it's best to observe them and where they'll be located in the sky at any time. It even compiles a list of the most suitable candidates for you.

This app has thousands of deep-sky targets organised by either catalogue or object type, and each one has its visibility shown on monthly, daily and hourly graphs - the feature that allows the user to get a full overview of their desired object. An enjoyable aspect is on the '24-Hour Visibility' chart: when the chosen target is at a desirable altitude at night, the line will go green, signalling that the object is at its astronomical best. This will help narrow down the many targets, but we feel that the Moon's visibility should have been incorporated as well, as this can play a big part in a target's visibility. Although we have emphasised the vast wealth of targets within this app, these are just deep-sky objects such as galaxies, star clusters, nebulae and other irregular objects. It does not include any objects in the Solar System, so if you're looking at the position of Jupiter or Saturn, then you would be out of luck.

Accessories Celestron Lens Pen

Cost: £12.00 (approx. $16.00) **From:** David Hinds Ltd

One smudge of a fingerprint or even a strand of hair lying across your optics can ruin a good observing session. There are many obstacles astronomers have to overcome in order to complete a successful night under the stars, such as clouds, humidity, light pollution and other atmospheric effects, but your telescope shouldn't be one of them. Celestron's double-sided lens pen is a handy tool that ensures you're always observing with the very best optical system your instrument can offer.

Fitted on one end is a retractable brush, designed to remove any pesky dust or other unwanted fragments, and at the other end is the soft cleaning tip that will handle the more arduous flakes. There are many benefits to this tool; it is lightweight, portable and there are no liquids or chemicals that could damage your equipment. It's also environmentally safe.

The thing that matters most, thought, is does it do the job? The answer to that is yes, and very well indeed. Without any hassle, it can clean up the optics of any piece of equipment, whether it is an eyepiece, a telescope or camera lens. Its small nature makes it easy to throw into your accessory bag, ready to bring out should a case of a dirty-optics emergency arise.

Program Space Engine

Cost: Free **From:** spaceengine.org

This universe simulator contains a wide variety of deep-space objects with accurate scientific information. A lot of plaudits have to go to Vladimir Romanyuk, the 'SpaceEngineer', as it combines great graphics, fine user interaction - all tied in with the wonders of the universe.

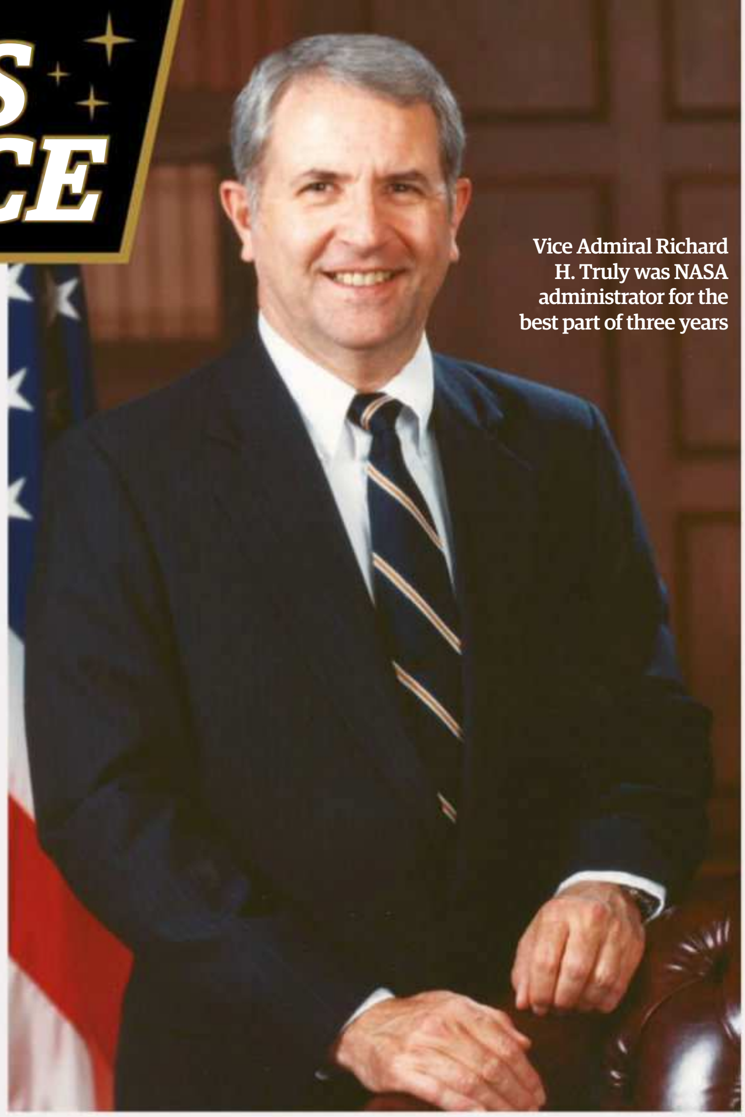
The latest version of the program, v.0.9.8.0, is only available on Windows and is free to download. From our experience, RAM of 8GB is recommended, as anything lower will struggle to cope with the large database and impressive graphics. This element is the aspect that impressed us the most: *Space Engine* adds a more realistic sense of adventure, and that is what you want when you're creating a computer simulator.

In terms of an astronomical point of view, *Space Engine* is extremely informative and contains an extensive database of planets, stars, star clusters, galaxies, nebulae, moons and others. Allowing the user to take their spacecraft several light years across the universe to check out different alien environments is something that we haven't seen in many universe simulators - a fantastic addition!

"This app has thousands of deep-sky targets organised by either catalogue or object type"

Richard H. Truly

The first NASA administrator to have also served as an astronaut



Vice Admiral Richard H. Truly was NASA administrator for the best part of three years

© NASA;

The first astronaut to become administrator of NASA, Richard H. Truly, had an extensive career serving his country while also leaving the confines of Earth on two occasions. His service to his country has led to multiple prestigious positions across a number of institutions, and he has a healthy medal collection to show for it. Born on 12 November 1937 in Fayette, Mississippi, United States, Truly was allured by aviation from an early age, and clearly showed that he was capable of great things as he reached the highest rank a Boy Scout of America can reach, Eagle Scout. His path through education led him down the engineering route, having received a Bachelor of Science degree in Aeronautical Engineering from the Georgia Institute of Technology in 1959.

The following year Truly's Naval career, which went on for over 30 years, began as a naval aviator. Truly has previously stated that he never had a lifelong desire to join the Navy, but instead it was just a career path he chose. Fortunately, this very wise career path is what led to him to become an astronaut and the key figure of the world's leading science and space exploration administration.

In August 1969, the NASA Astronaut Corps had a new member in the shape of Truly, who spent four years training and preparing before he was finally involved with a space mission. In 1973, Truly was a member of the astronaut support crew and capsule communicator, also known as CAPCOM, for all three manned Skylab missions in 1973. Truly was also CAPCOM for the first joint US and Soviet Union flight, the Apollo-Soyuz mission in 1975.

Afterwards he began actually flying. The first flying experience Truly had in regards to his astronaut career was piloting one of the Approach and Landing Tests of the Space Shuttle Enterprise in 1977. The first time Truly got to experience the nothingness of space firsthand was in 1981, when he was pilot of the STS-2 mission, the second Space Shuttle mission that included the spacecraft Columbia. Truly made a return to space in 1983, when he commanded the STS-8 mission on board Space Shuttle Challenger.

When Truly retired from the skies, he took up the ground-based position of NASA's associate administrator for space flight just three weeks after the tragic Challenger disaster. This involved a careful evaluation of the entire situation, which could not have been an easy task. After 31 months a Space Shuttle finally flew again, having learned important key lessons from the tragedy.

Following this position, Truly became a Vice Admiral of the Navy, and the morning after he stepped down from this position he was sworn in as the eighth administrator of NASA under the tenure of George H. W. Bush.

For three years Truly reigned supreme over NASA, leading it through a rough time, including a harsh feud with the National Space Council. Unfortunately, President Bush relieved Truly of his duties in 1992 with no clear reason why. This is just one minor blip in what can be considered a very impressive and memorable career with NASA, whether it was venturing to the farthest frontiers in human space exploration or calling the shots across the entire administration.

Truly started off working as a naval aviator for the US Navy

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